St. Louis River Watershed Stressor Identification Report

A descriptive phrase or sentence in plain language. Tips: Avoid repeating the word "report" if already used above. Active voice is better.

Changing the cover color is allowed. The Design Team will give advice on colors or photos.

Minnesota Pollution Control Agency

October 2013

Legislative charge

Insert Legislative Charge language here if there is one. Otherwise, delete.

Authors

Principal Author
Other author
Other author

Contributors/acknowledgements

Name
Name

Editing and graphic design

PIO staff
Graphic design staff
Administrative Staff

Estimated cost of preparing this report *(as required by Minn. Stat. § 3.197)*

Total staff time: xx hrs.	$xx,xxx
Production/duplication	$x,xxx
Total	$xx,xxx

The MPCA is reducing printing and mailing costs by using the Internet to distribute reports and information to wider audience. Visit our website for more information.

MPCA reports are printed on 100% post-consumer recycled content paper manufactured without chlorine or chlorine derivatives.

Minnesota Pollution Control Agency

520 Lafayette Road North | Saint Paul, MN 55155-4194 | www.pca.state.mn.us | 651-296-6300

Toll free 800-657-3864 | TTY 651-282-5332

This report is available in alternative formats upon request, and online at www.pca.state.mn.us .

Document number: xxx-xx-xxxxx

Foreword

Insert Foreword language here if there is one. Otherwise, delete.

Contents

Section I – Introduction / Report Purpose

1. **Report Purpose and Process Overview**
   WRAPS, Stressor ID
2. **St Louis River Watershed Zones**
3. **Biological Impairments**
   Summary of impairments and symptoms

Section 2 – Broad Level SID-Recon / Identify Candidate Causes by Watershed Zone

Hydrology

- Evaluate hydrology of SLR watersheds, with particular emphasis on the impaired sub-watersheds. If there is sufficient evidence that altered hydrology is a stressor for any one stream in a watershed zone, it should be listed as a candidate cause (to be evaluated in Section 3). Example – Stony Creek watershed is 90% channelized – it's within MDFPB watershed zone, so altered hydrology is a candidate cause for impairment that will be further analyzed for that zone.

Water Chemistry

Geomorphology

Connectivity

Biology (Stressors)

Section 3 – Causal Analysis of Candidate Causes for Each Watershed Zone

Duluth Urban Trout Streams

- Evaluate each candidate stressor (determined from section 2) at "detailed level"
- Weight of Evidence Scoring for impairments

Report Purpose, Process, and Overview

{Insert M. Kennedy WRAPS Overview}

Overview of Stressor Identification

The stressor identification process (SID) is used in this report to weigh evidence for or against various candidate causes of biological impairment (see Cormier et al., 2000). The SID process is prompted by biological assessment data indicating that a biological impairment has occurred. Through a review of available data, stressor scenarios are developed that may accurately characterize the impairment, the cause, and the sources/pathways of the various stressors (Figure 3). Confidence in the results often depends on the quality of data available to the SID process. In some cases, additional data collection may be necessary to accurately identify the stressor(s).

SID draws upon a broad variety of disciplines, such as aquatic ecology, geology, geomorphology, chemistry, land-use analysis, and toxicology. Strength of evidence (SOE) analysis is used to develop cases in support of, or against various candidate causes. The scoring scale for evaluating each type of evidence in support or against a stressor is displayed in Appendix B. Typically, the majority of the information used in the SOE analysis is from the study watershed, although evidence from other case studies or scientific literature can also be drawn upon in the SID process.

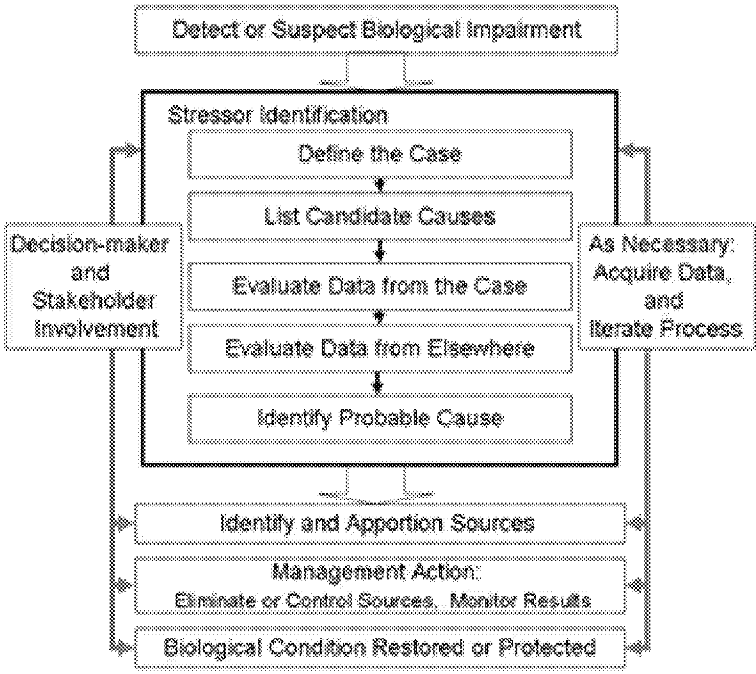


Figure 1: Conceptual model of SID process

Completion of the SID process does not result in a finished Total Maximum Daily Load (TMDL) allocation. The product of the SID process is the identification the stressor(s) for which the TMDL load allocation will be developed. For example, the SID process may help investigators identify excess fine sediment as the cause of biological impairment, but a separate effort is then required to determine the TMDL and implementation goals needed to address and correct the impaired condition.

Strength of evidence scoring

The relationships between stressor and biological response are evaluated by considering the degree to which the available evidence supports or weakens the case for a candidate cause. A standard set of scores recommended by the U.S. Environmental Protection Agency (EPA) were used to tabulate scores for each candidate cause. These scores are described in Table 1.1. For additional information on the scoring process, visit the EPA CADDIS website on scoring (http://www.epa.gov/caddis/si_step_scores.html).

Table 1.1: Strength of evidence scoring criteria

Score	Interpretation
+ + +	This finding *convincingly supports* the case for the candidate cause
+ +	This finding *strongly supports* the case for the candidate cause, but is not convincing due to potential confounding
+	This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because coincidence and errors may be responsible.
0	This finding *neither supports nor weakens* the case for the candidate cause
-	This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening because coincidence and errors may be responsible
- -	This finding *strongly weakens* the case for the candidate cause, but is not convincing because the exposure or the mechanism may have been missed
- - -	This finding *convincingly weakens* the candidate cause
NE	No evidence of this type available

St. Louis River Watershed Zones

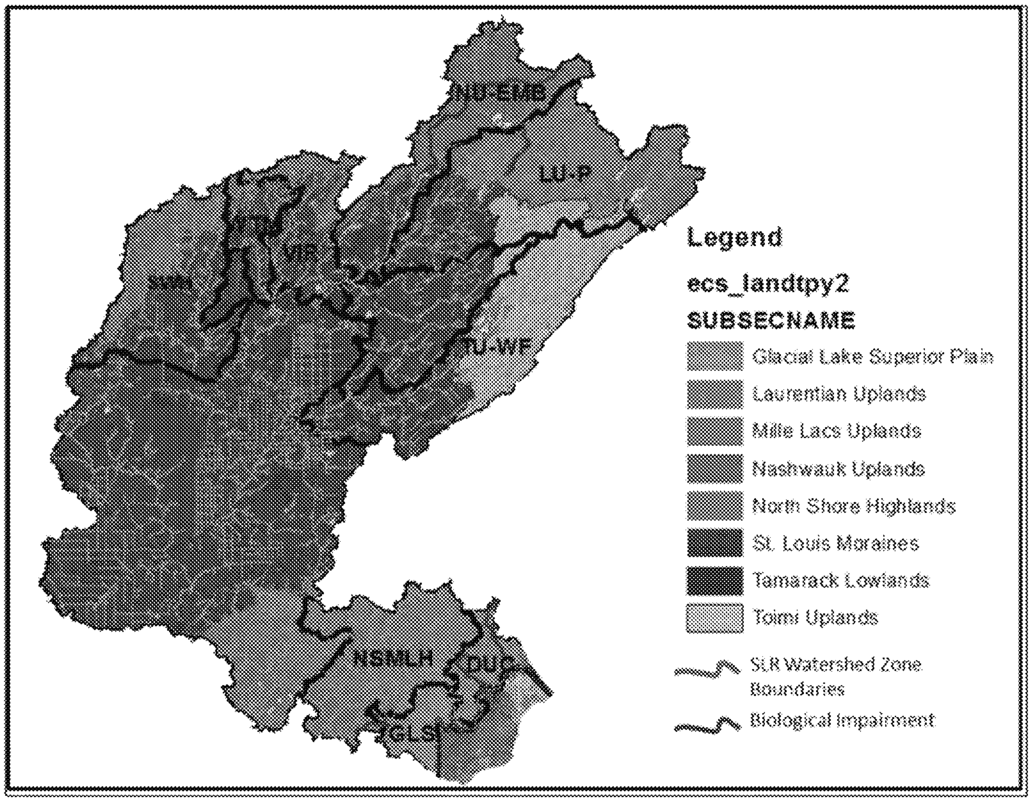
The St. Louis River (SLR) watershed drains approximately 3,584 square miles of a landscape that has one of the most complex geologic histories of any region in the world. The size and complexity of the SLRW makes it difficult to evaluate potential stressors without further stratifying the drainage area into smaller sections. Although there may be some consistent chemical and physical stressors found throughout, several stressors are likely acting locally, driven by characteristics specific to a certain region of the watershed. For the purpose of investigating the causes of biological impairments in this report, the SLRW was stratified into eleven "watershed zones" based on similarities in local geology, land-use, hydrology, and ecological classifications. These watershed zones will serve as an organizational framework for presenting data in this Stressor ID report. Each impairment will be discussed and evaluated individually, but the watershed zone groupings will help to place these impaired waters within the overall context of the SLR watershed.

Delineation of SLR Watershed Zones

The delineation of SLRW watershed zone boundaries is heavily based on the Minnesota Ecological Classification System (ECS), which was developed through a collaborative effort between MN DNR and the United States Forest Service (USFS). The primary function of the ECS is to map and describe progressively smaller areas of land with increasingly uniform ecological features. Associations of biotic and environmental factors, such as climate, geology, topography, soils, hydrology, and vegetation are all incorporated into the ECS sections and sub-sections.

Six ECS subsections occur within the SLRW; Glacial Lake Superior Plain, Laurentian Uplands, Mille Lacs Uplands, Nashwauk Uplands, St. Louis River Moraines, Tamarack Lowlands, and Toimi Uplands. These subsections were used as an initial framework for identifying unique regions of the SLRW that may share similar natural background conditions and tendencies toward specific regional stressors. The subsections were further divided into eleven watershed zones based on known anthropogenic disturbances that are likely to present different stressor scenarios than neighboring watershed zones with similar natural background conditions. Examples of these anthropogenic factors include channelization and ditching of streams, the presence or absence of mining land-uses, urbanization, and industrial or municipal wastewater discharges.

Appendix BLANK provides a summary of the geology, hydrology, land-uses, and impaired streams found within each watershed zone. Throughout this report, these eleven watershed zones will be used as a framework for conveying environmental data and conclusions on candidate causes for biological impairment. Additionally, the watershed zone framework serves as an important tool for identifying watershed protection and restoration strategies that can be applied on a much larger scale than an individual impaired stream and its watershed.


NU-EMB
LU-P
VIR
SWH
TU-WF
NSMLH
DUC
GLS
Legend
ecs_landtpy2
SUBSECNAME
Glacial Lake Superior Plain
Laurentian Uplands
Mille Lacs Uplands
Nashwauk Uplands
North Shore Highlands
St. Louis Moraines
Tamarack Lowlands
Toimi Uplands
SLR Watershed Zone Boundaries
Biological Impairment

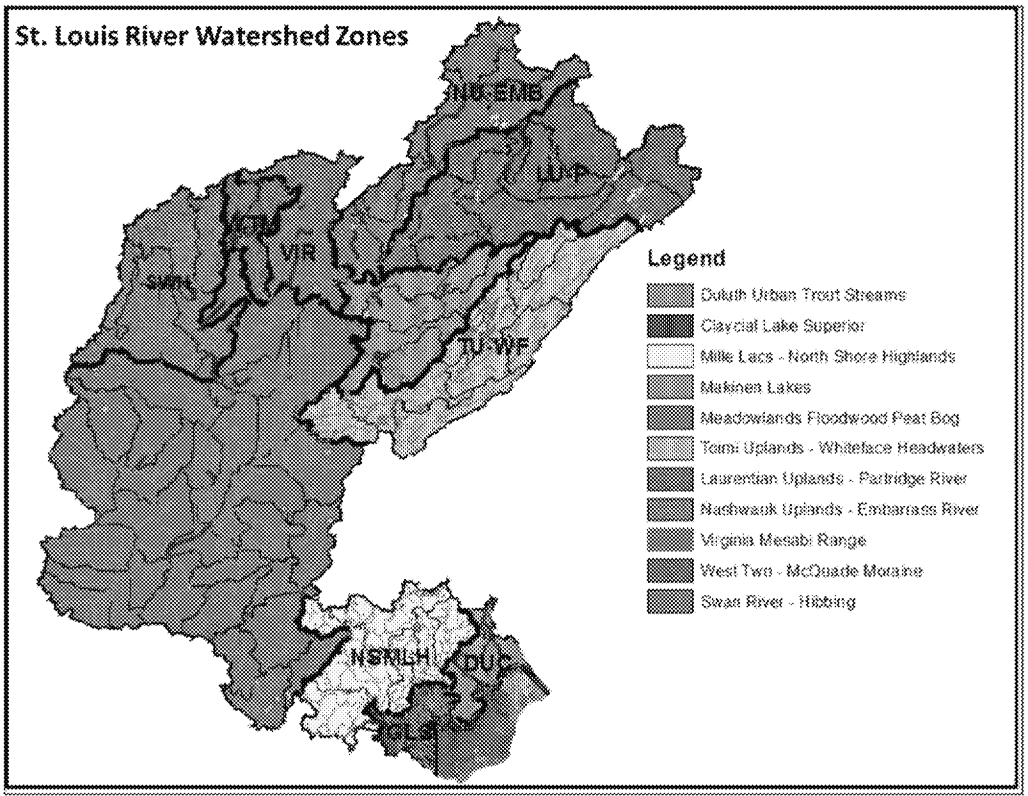


Figure Blank - The eleven watershed zones of the SLRW

St. Louis Watershed Characterization

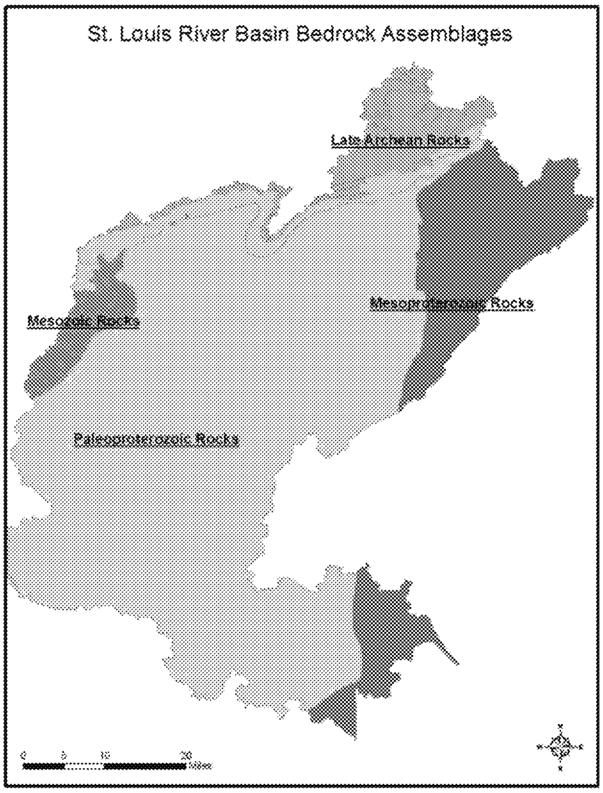
Bedrock geologic history of the St. Louis River Basin

The bedrock geology of the St. Louis River basin is ancient and complex. There are four main assemblages representing four very different geologic conditions in Minnesota's past (Figure's X and X). The oldest rocks are found in the northernmost regions of the watershed - north of the Mesabi and Cuyuna iron ranges. These rocks date from the Archean period of geologic history and are between 2.5 and 3.0 billion years old. Igneous and metamorphic rock types are dominant and were formed when present-day Minnesota was at the margin of an expanding North American continent.

The second assemblage underlies most of the central portion of the watershed and is from the Animikie Group of Paleoproterozoic rocks – between 1.8 and 2.5 billion years old. Noteworthy among this assemblage are the economically important iron formations, which are metamorphosed oceanic sediments deposited over 2 billion years ago. The conditions for banded iron deposition stopped for unknown reasons about 1.85 billion years ago; thus began the deposition of the second major unit in the Animikie Group. The Virginia formations of shale, siltstone, and greywacke were laid down as oceanic sediments and metamorphosed in a mountain-building event known as the Penokean orogeny. These rocks are mostly covered with recent glacial deposits, but outcrop at the southern base of the Iron Range and more notably along the St. Louis River at Jay Cooke State Park.

The third major geologic assemblage in the St. Louis River basin contains rocks from the Mesoproterozoic and are roughly 1.1 – 0.9 billion years old. These rocks were created in a time during which the North American continent experienced a major rifting event similar to the present-day East-African rift. As the continent began to split apart, volcanic activity increased dramatically and lava poured out in massive flows. The weight of the flows caused the crust to sink and the edges of the rift zone to tilt inwards. The resulting basin collected vast quantities of sediments eroding from the barren landscape – now known as the Hinckley Sandstone and Fold du Lac Formation. The volcanic and metamorphic rocks in this assemblage are erosion-resistant and create the conditions for some of the higher gradient streams in the eastern portions of the St. Louis River watershed.

The final and youngest geologic assemblage in the basin is the Coleraine Formation of the Cretaceous period (~100 million years old). This group's extent is somewhat minor and only occurs in the western half of the Swan River watershed. The Coleraine Formation consists mostly of marine sediments deposited when an inland sea invaded Minnesota from the west.



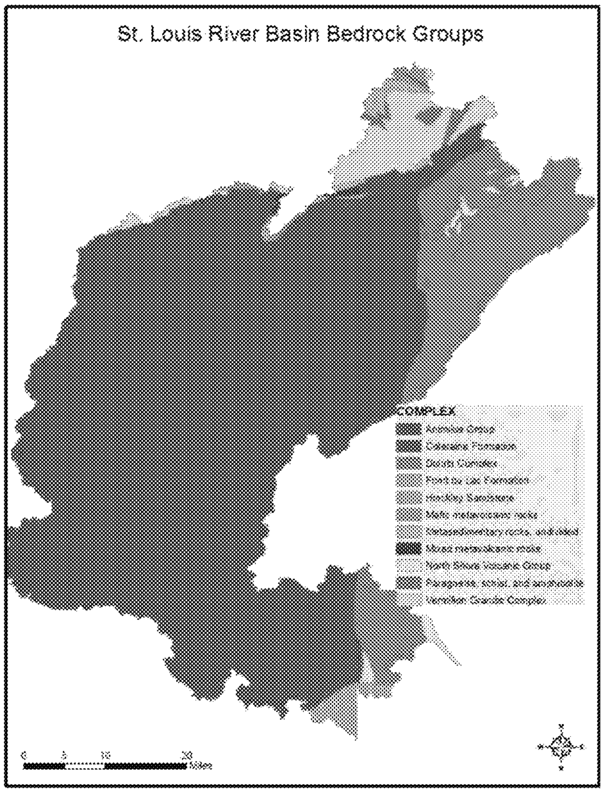


Figure X: Major bedrock assemblages of the St. Louis River watershed

Figure X: Bedrock groups of the St. Louis River watershed

Glacial History of the St. Louis River Basin

Despite the complex, 3 billion year geologic history of the basin, almost all of the topography and surficial geology that we see today is the result of only 40,000 years of glacial activity. The ice age and continental glaciers of the Pleistocene Era (10-50 thousand years ago) can be divided into three major periods (see Figure X). The first period of glacial advance came from the northeast and deposited an iron-rich red drift that forms the moraines that extend from Brookston to southwest Lake County and then toward Hibbing. The next period saw the St. Louis SubLobe advance from the northwest pushing a lime-rich drift. This lobe formed the moraines that run northeast to southwest, called the Toimi drumlins, and make up much of the Cloquet and Whiteface River watersheds. In the final period, the Superior Lobe advanced from the northeast out of the Lake Superior basin and deposited a rocky infertile drift along the southern and eastern edge of the St. Louis River watershed. These deposits essentially dammed the meltwaters of the retreating glaciers and formed an immense, shallow lake called Glacial Lake Upham.

It is the bed of this historic lake that comprises the majority of the central part of the St. Louis River watershed and is responsible for the extremely low gradients found there. Tributaries of note in this area are the Swan, Whiteface, Floodwood, and Savanna Rivers. Bogs and peatland dominate this region due to the limiting effect of the underlying Virginia Slate on the movement of groundwater. Warm-water conditions are prevalent due to the relative lack of springs and the surface water-fed tributaries (Lindgren, et al., 2006, *A Study of the St. Louis River*, MN DNR Section of Fisheries).

The southern portion of the watershed - the Mille Lacs – North Shore Highlands and Glacial Lake Superior watershed zones - contain tributaries fed by springs flowing through the course sediments of the moraines that held back Glacial Lake Upham. The higher gradients of these zones created the conditions for five hydroelectric facilities to be built on the St. Louis River. Major tributaries in this area are Otter Creek, Midway River, and Pine River.

The eastern St. Louis watershed has a moderate gradient that drains the moraines deposited by all three previously discussed glacial eras. Sediments tend to be very course and productive as a result of lime contained in glacial drift (Lindgren, et al., 2006). The Toimi Uplands watershed zone and eastern portions of the Makinen Lakes and Laurentian Uplands are contained within this area.

The northern part of the watershed includes the Laurentian and Nashwauk Uplands, Virginia Mesabi Range, West Two, and Swan River watershed zones. This area primarily drains infertile red glacial drift. Significant tributaries include East and West Two Rivers, Embarrass and Partridge Rivers.

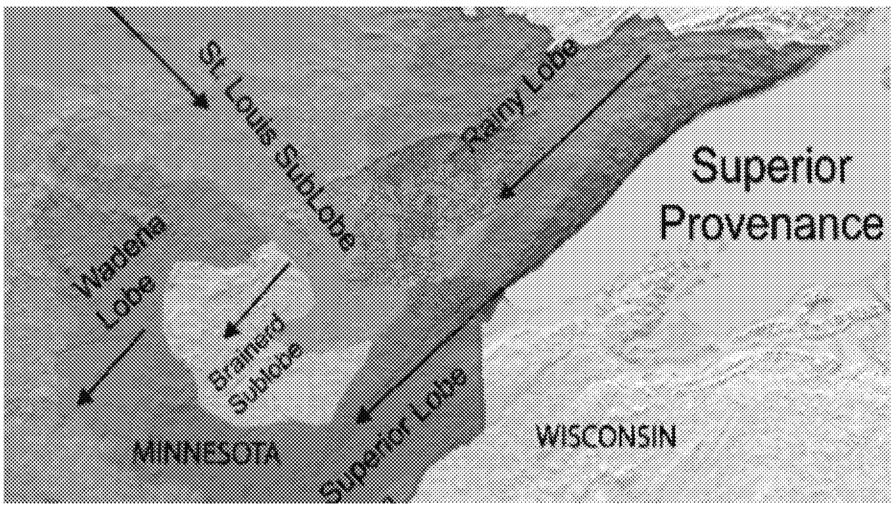


Figure X: Major glacial movements in Northeast Minnesota. www.mngs.umn.edu

Biology

The St. Louis River watershed (SLRW) spans one of the most diverse landscapes in Minnesota in terms of geological and hydrological features. Consequently, there are a wide variety of aquatic habitats present within its 3,443 mi^2 watershed area, which in turn support a diverse population of aquatic organisms. Over 50 species of fish have been documented in the streams and rivers of the SLRW during MPCA and DNR biological monitoring efforts spanning the years 1967 – 2012. The most common gamefish sampled (in streams and rivers) over this period include smallmouth bass and northern pike from watermwater streams, and brook and brown trout from coldwater streams.

Coldwater trout streams are common in the southern portion of the SLRW, particularly in the steep, rugged drainages that feed St. Louis Bay, and in areas of glacial till deposits near Cloquet, Minnesota. Several tributaries to the Swan River, Whiteface River, and Partridge River are also designated trout streams, although the number and quality of coldwater streams in these regions is generally much lower. There is a long history of trout stocking in the watershed, dating back to failed attempts to stock pacific salmon into the St. Louis River estuary and cold water tributaries in 1875 (Lindgren, ????). Stocking of brook trout, brown trout, and rainbow trout has occurred throughout the watershed since 1894, but current stocking efforts are limited to a small number of streams, most of which are near the city of Duluth. Today, brook trout and brown trout are the only salmonids commonly found in streams in the SLRW. A map showing the distribution of brook trout (*Salvelinus fontinalis*) and brown trout (Salmo trutta) is shown in figure BLANK.

(MAP OF BKT/BNT distribution)

Minnesota's list of endangered, threatened or special concern species includes several fish species known to have historic ranges within the SLRW. These include lake sturgeon (Acipenser fulvescens), least darter (Etheostoma microperca), and pugnose shiner (*Notropis anogenus*). There are no recorded observations of these species in MPCA's biological monitoring records, which include 313 sampling visits at sites within the watershed. Populations of these fish within the SLRW may have been reduced due to increased presence of the stressors highlighted in table BLANK. Numerous species of threatened or endangered caddisflies and dragonflies have historic ranges within the SLRW. However, MPCA macroinvertebrate data does not include species-level identification, making it difficult to know if any of these organisms were collected in the samples.

Table BLANK:

Common Name *(Scientific Name)*	Status	Year Listed	Specific Impacts / Stressors
Lake Sturgeon (*Acipenser fulvescens*)	SC	1984	Siltation, some agricultural practices, and dam construction reduced habitat availability for the species, resulting in the extirpation or reduction of populations throughout its range (MN DNR)
Least Darter (*Etheostoma microperca*)	SC	1996	Pollution from pesticides, agricultural and urban runoff, eutrophication, and loss of habitat elements such as low velocity waters and aquatic vegetation. Loss of forested habitats around streams, stream reclamation, and the introduction of non-native and predatory fish species (MN DNR)
Pugnose Shiner (*Notropis anogenus*)	T	1996	Extremely sensitive to increases in turbidity and siltation. Removal of littoral vegetation from lakes and an increase in turbidity in lakes and

			streams are linked to its demise in other states (MN DNR)
T = Threatened SC = Special Concern			

Historic and Contemporary Monitoring Efforts

The streams and rivers of the St. Louis River watershed have been studied extensively by many interest groups and government agencies. Over the past century, Several MN DNR reports offer a thorough overview of the St. Louis This report will focus primarily on data collected during MPCA's Intensive Watershed Monitoring (IWM) efforts during the years 2009 – 2013.

{Mention Lindgren study….others too…Berndt)

Biological Data

This report draws upon biological and habitat data contained within MPCA's biological monitoring database. Quality assurance protocols have been used to ensure data quality, which has allowed MPCA to use data from other contributing government agencies (namely MN Deparment of Natural Resources) also carrying out biological assessment work in the same region. Data from each sampling visit has been quality coded using the criteria listed in table BLANK. The biological data presented in this report are derived only from the monitoring visits deemed "reportable" or "replicate" by MPCA biologists (table BLANK).

Data Quality	Description	Fish		Invert	
		Sites	Visits	Sites	Visits
Reportable / Not Assessable *	Data quality is good, but not useable assessment purposes (channelized or low sample size)	37	37	42	45
Reportable / Assessable *	Data quality is good, useable for assessments.	134	134	122	132
Replicate *	Repeat visit to an existing station	48	55	29	33
Non-Reportable **	Data quality is questionable or poor.	89	90	4	4

* Data will be used in SLRW SID Report ** Data will not be used in SLRW SID Report

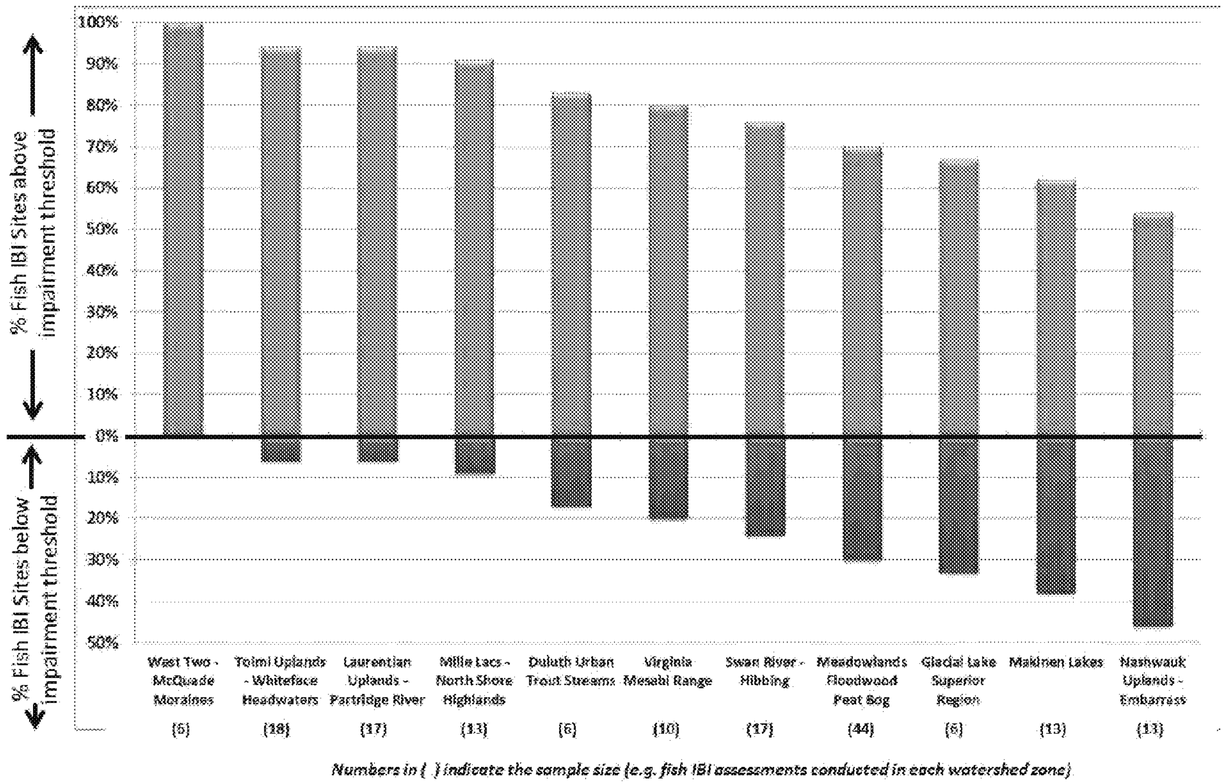
General Overview of Biological Integrity Results by Watershed Zones

Fish and macroinvertebrate data were analyzed in the context of watershed zones in order to evaluate large-scale spatial trends in biological integrity. Two watershed zones in the SLRW consistently show a high level of biological integrity based on both fish and macroinvertebrate results – Toimi Uplands-Whiteface Headwaters (TU-WF) and the Laurentian Uplands-Partridge River (LU-P). In the TU-WF, 17 of 18 sites (94%) fish assessment sites scored above the impairment threshold. These sites generally exceeded the threshold by a wide margin (average of 27 points above threshold). The MIBI results are equally as impressive in the TU-WF watershed zone. Similar to the fish IBI results, 94% of the stations sampled scored above the MIBI impairment threshold, and the average margin above the threshold was 27 points. Index of biological integrity scores in the LU-P were slightly lower in comparison to those in the TU-WF, but still exceeded the impairment threshold at a high rate (94% of FIBI scores and 92% of MIBI scores).

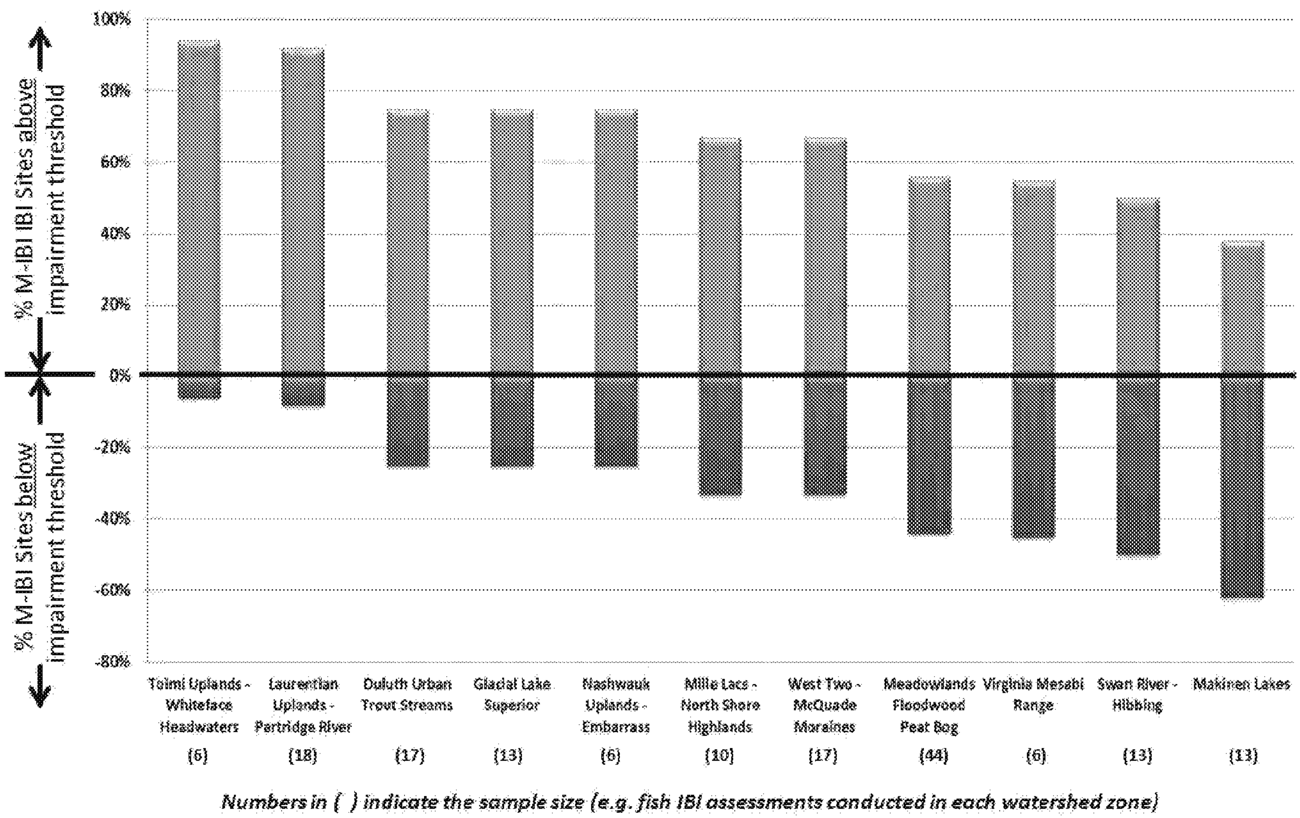
The exceptional biological integrity observed within these two watershed zones can be attributed to lower anthropogenic influence, as well as several natural background characteristics that are favorable for supporting healthy streams. Very few of the streams in these two watershed zones have been ditched and straightened, and wetland areas have generally not been altered or drained. Consequently, many of the streams assessed in this region of the SLRW remain in stable physical and hydrological condition and provide exceptional habitat for aquatic life. Relative to other areas of the SLRW, land-cover within the TU-WF and LU-P watershed zones has changed very little from pre-settlement. Less than 2% of the land-area in both of these watershed zones is catergorized as "developed" based on National Land Cover Database (NLCD) data from 2006. Moraine and outwash geological features are common throughout these two watershed zones. The rolling terrain and coarse textured soils found in large portions of these watershed zones facilitates groundwater to surfacewater exchange, resulting in cooler water temperatures and more stable baseflows for sensitive aquatic life. In addition, the coarser grained material and steeper slopes found in this geologic setting provide a high level of in-stream habitat complexity (riffles, boulders, gravel spawning habitat) that is not found in lower gradient, bog and wetland dominated regions of the SLRW.

Although biological impairments were observed in nearly every region of the SLRW, several watershed zones were found to produce consistently lower IBI scores for fish and macroinvertebrates. Within the Makinen Lakes (ML) zone, over 38% (5 of 13) of the fish assessments resulted in IBI scores below the impairment threshold. Although a relatively high percentage of sites scored below the impairment threshold, the fish communities observed within the ML watershed zone were not severely degraded, with the exception of sites on Paleface River and Paleface Creek. The ML watershed zone had the highest percentage of MIBI stations score below the impairment threshold (62%). Paleface Creek, Paleface River, and Water Hen Creek were all found to have severely degraded macroinvertebrate assemblages. Two impaired streams in this watershed zone (Paleface Creek and Water Hen Creek) are fed by lakes that are listed as impaired for excess nutrients. The significant amount of wetlands in this watershed zone and low gradient nature of these streams may also be natural background stressors contributing to low IBI scores. These, and other stressors in this watershed zone will be evaluated throughout this report.

The highest rate of FIBI scores below the impairment threshold (54% / 7 of 13) was found in the Nashwauk Uplands – Embarrass River (NU-EMB) watershed zone. Low scoring FIBI sites within this watershed were primarily located on the upper Embarrass River and several of its small tributary streams. Fish results from the upper Embarrass River (the portion upstream of the town of Embarrass) show extremely low fish counts and limited taxa richness. The impaired reach of the Embarrass River flows through expansive wetlands, resulting in extremely tannin stained (tea colored) water that is often low in dissolved oxygen. Two of the impaired streams in this watershed zone, Spring Mine Creek and the Embarrass River, have watersheds that have been heavily altered by resource extraction land-uses such as logging and mining. Both of these streams are discharge points for mine pit dewatering, and water quality sampling results from these streams show elevated specific conductance and sulfate concentrations. These potential stressors will evaluated in terms of their impact to aquatic life in these watersheds in sections BLANK.



% Fish IBI Sites above impairment threshold
% Fish IBI Sites below impairment threshold
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
10%
20%
30%
40%
50%
West Two - McQuade Moraines
Toimi Uplands - Whiteface Headwaters
Laurentian Uplands - Partridge River
Mille Lacs - North Shore Highlands
Duluth Urban Trout Streams
Virginia Mesabi Range
Swan River - Hibbing
Meadowlands Floodwood Peat Bog
Glacial Lake Superior Region
Makinen Lakes
Nashwauk Uplands - Embarrass
(6)
(18)
(17)
(13)
(6)
(10)
(17)
(44)
(6)
(13)
(13)
Numbers in ( ) indicate the sample size (e.g. fish IBI assessments conducted in each watershed zone)



% M-IBI IBI Sites above impairment threshold
% M-IBI Sites below impairment threshold
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
Toimi Uplands - Whiteface Headwaters
Laurentian Uplands - Partridge River
Duluth Urban Trout Streams
Glacial Lake Superior
Nashwauk Uplands - Embarrass
Mille Lacs - North Shore Highlands
West Two - McQuade Moraines
Meadowlands Floodwood Peat Bog
Virginia Mesabi Range
Swan River - Hibbing
Makinen Lakes
(6)
(18)
(17)
(13)
(6)
(10)
(17)
(44)
(6)
(13)
(13)
Numbers in ( ) indicate the sample size (e.g. fish IBI assessments conducted in each watershed zone)

Geomorphology

Summary of St. Louis River Geomorphology

St. Louis River watershed streams were profiled (Figure X) using LiDAR-derived digital elevation models and the 3D Analyst extension for ArcMap, which shows the change in elevation of a surface along a line. For example, a 3D line drawn on a digital elevation model up the center of a river will show its profile, or a line drawn perpendicular to a valley will show the cross-section for that valley. All impaired streams in the St. Louis River watershed were profiled, as well as the main stems of major tributaries such as the Whiteface, Floodwood, Savanah, Midway, and Artichoke Rivers. 980 miles of stream and 516 reaches were then delineated based on slope, Rosgen channel type and valley type (descriptions of channel and valley types are shown in Figures X and X). For more information on the stream types see “A Classification of Natural Rivers” (Rosgen 1994). Channel types were identified using a combination of aerial and field photos, slope, sinuosity, and stream cross-sections. Valley types were identified using slope, valley cross-sections, and photos.

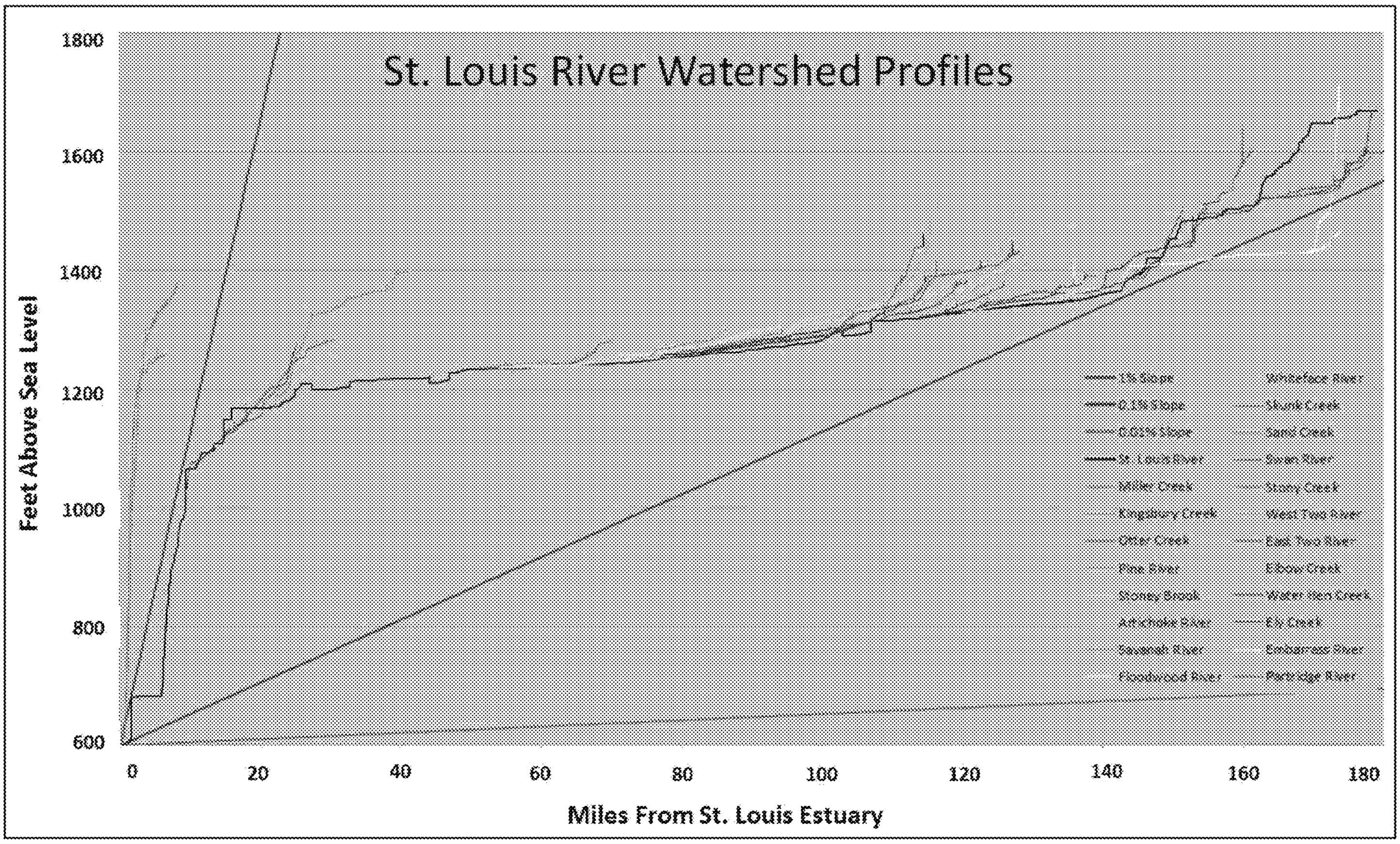
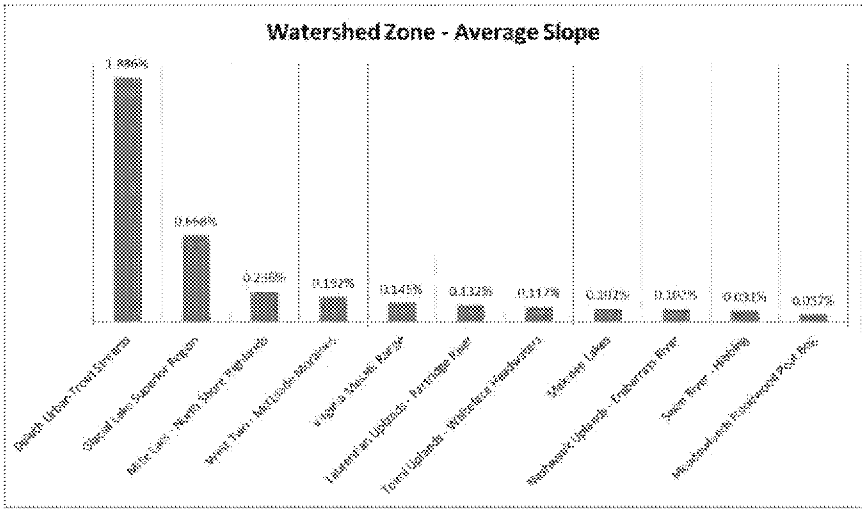


Figure X: Profile of the St. Louis River and all major tributaries, with 1%, 0.1%, and 0.01% slope lines for reference

Figure X shows the average slope for each watershed zone. Not surprisingly, the Duluth Urban Trout Stream zone is the steepest with an average slope of almost 1.89% (100 feet per mile of stream). Rivers in the Meadowlands Floodwood Peat Bog are the flattest with an average slope of 0.057% (3 ft/mile). {add some additional text – e.g. rammifications of stream slope for aquatic habitat}



Figures X-X show the stream and valley type breakdown of each watershed zone. Historic lacustrine valley and alluvial valley types (VIII and X) constitute 60-80% of the St. Louis River watershed zones. Common within these valley types are low gradient stream types such as Cc and E. These are predominant within the St. Louis River watershed. However, Miller and Kingsbury Creeks in the Duluth Urban Zone are dominated by altered channels and steeper channels such as Aa+, A and B.

	Stream Types (%)											
Watershed Zones	Aa+	A	B	Bc	C	Cc	D	E	F	Gc	Altered Channel	Lake
Duluth Urban Trout Streams	4.80%	8.57%	7.39%	2.47%	12.84%			18.02%			45.91%	
Glacial Lake Superior Region					24.10%				25.76%			50.13%
Laurentian Uplands - Partridge River			0.17%	0.61%	13.91%	34.36%	1.27%	32.09%			2.76%	14.82%
Makinen Lakes		0.06%	0.07%	0.83%	5.31%	17.44%	0.73%	66.69%			4.08%	4.78%
Meadowlands Floodwood Peat Bog		0.12%		0.50%	3.39%	61.55%	0.18%	24.45%			8.84%	0.97%
Mille Lacs - North Shore Highlands			0.80%	2.89%	14.25%	4.53%	1.40%	45.32%	22.42%		5.64%	2.75%
Nashwauk Uplands - Embarrass River			1.39%	2.00%	2.08%	19.58%	0.58%	47.05%		4.45%	8.26%	14.61%
Swan River - Hibbing			0.12%	0.58%	13.48%	51.30%		32.03%			1.88%	0.61%
Toimi Uplands - Whiteface			0.31%	0.71%	9.73%	42.74%		40.28%				6.24%
Virginia Mesabi Range				2.93%	14.96%	10.38%	4.16%	59.05%			5.72%	2.80%
West Two - McQuade Moraines			0.25%	2.19%	30.06%	7.12%		43.62%			3.38%	13.38%
Grand Total (%)	0.07%	0.17%	0.39%	1.18%	10.09%	33.16%	0.73%	39.74%	2.42%	0.33%	5.46%	6.27%
Grand Total (mi)	0.73	1.64	3.78	11.60	98.81	324.77	7.12	389.18	23.65	3.27	53.44	61.40

		Valley Types (%)										
		I	II	III	IV	V	VI	VIII	X	XI	Altered Valley	Lake
Watershed Zones	Duluth Urban Trout Streams	2.12%	5.73%	2.45%		7.75%	16.81%	11.70%	47.80%		5.63%	
	Glacial Lake Superior Region						34.93%	14.93%				50.13%
	Laurentian Uplands - Partridge River					10.05%		20.19%	56.92%		2.76%	10.08%
	Makinen Lakes	0.06%	0.39%			2.32%		22.24%	70.22%			4.78%
	Meadowlands Floodwood Peat Bog	0.12%			21.08%	7.89%		42.10%	27.53%	0.31%		0.97%
	Mille Lacs - North Shore Highlands		0.61%	0.38%	13.75%	11.20%	10.13%	13.68%	47.51%			2.75%
	Nashwauk Uplands - Embarrass River		6.49%			0.17%		31.45%	46.84%		0.43%	14.61%
	Swan River - Hibbing		2.03%		1.79%	3.16%		62.58%	29.83%			0.61%
	Toimi Uplands - Whiteface				0.41%	19.10%		26.10%	47.74%	0.41%		6.24%
	Virginia Mesabi Range				5.02%	2.93%		56.90%	26.63%		5.72%	2.80%
	West Two - McQuade Moraines		0.25%			9.18%		33.32%	41.67%		2.20%	13.38%
	Grand Total (%)	0.07%	0.90%	0.07%	6.57%	7.58%	1.61%	33.16%	43.34%	0.11%	0.94%	5.65%
	Grand Total (mi)	0.66	8.82	0.73	64.35	74.26	15.72	324.76	424.49	1.12	9.18	55.30

Water Quality

St. Louis River Watershed Reference Sites

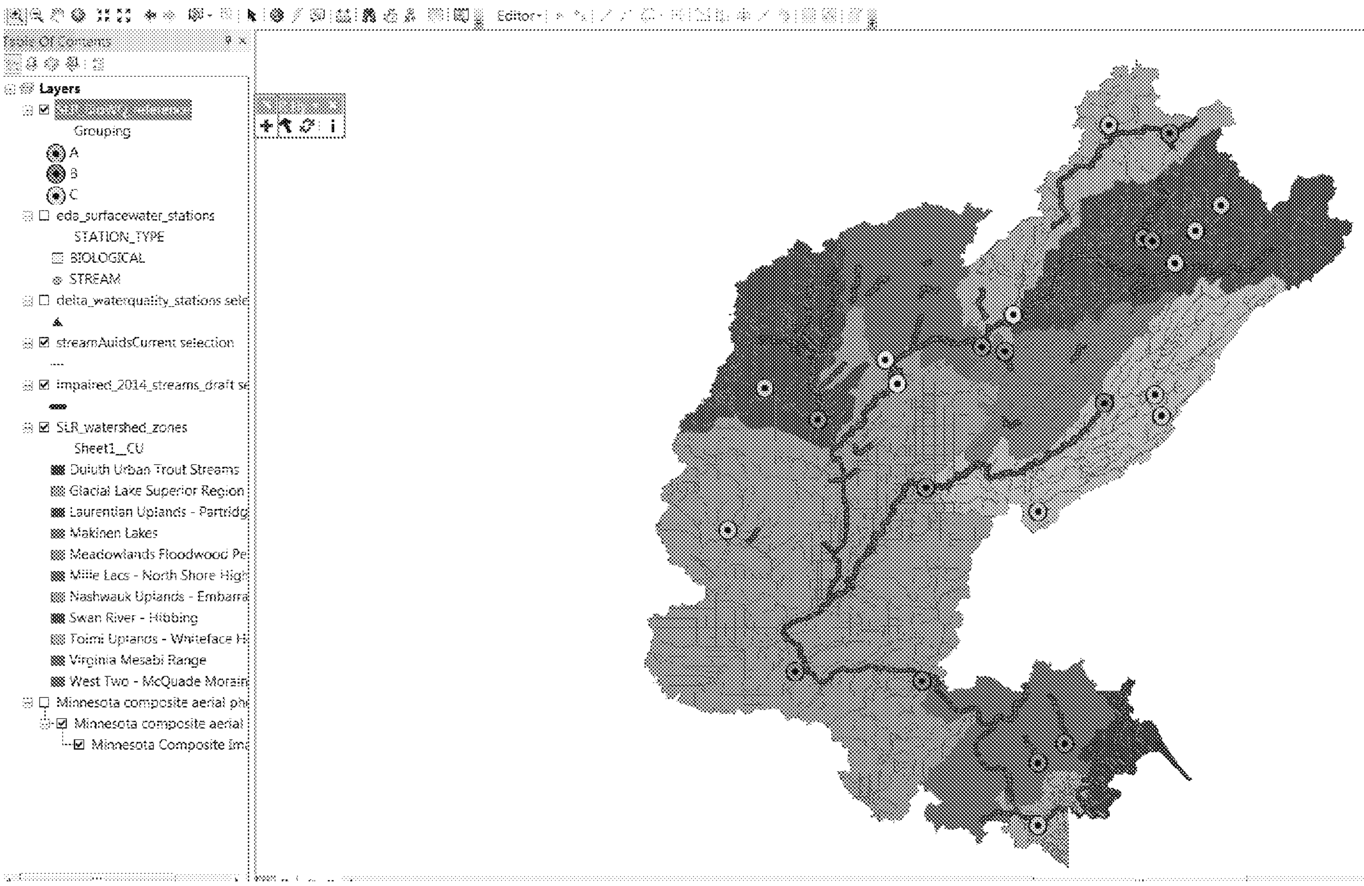
Twenty-five monitoring sites were selected in the St. Louis River watershed in attempt to character water quality conditions at sites with good to excellent index of biological integrity (IBI) results. The majority of these monitoring stations scored above the upper confidence limit (UCL) for both fish and macroinvertebrate IBI. However, there are several sites that were included based on one biological assessment criteria alone (MIBI or FIBI), and a select few that were chosen more based on lack of human disturbance.

Group A

Monitoring sites included in group A are located in watersheds with minimal anthropogenic disturbance. Generally, sites in this grouping are not influenced by

Stream	Group	Wzone	EQUIS ID	Bio Site(s)	FIBI Class	MIBI Class	+ / - FIBI U.C.L	+ / - MIBI U.C.L	Lat	Long
Little Silver Creek	A	GLS	S000-616	none	-	-	-	-	46.64167	-92.35642

Colvin Creek	A	LU_Partridge	S002-593	09LS106	7	4	+8	+9	47.52805	-91.99802
SB Partridge R	A	LU_Partridge	S005-767	97LS077	6	3	+5 / +6	+15 / -3	47.56591	-91.94100
St. Louis River	A	LU_Partridge	S000-631	97LS080	5	3	+17 / +25	+31 / +7	47.47980	-92.04330
Floodwood River	A	MDWLANDS	S005-761	09LS027	7	4	- 9	-5	47.08582	-93.03022
Bear Creek	A	NU_EMB	S006-543	09LS098	7	4	-7	+1	47.68798	-92.18692
Trib to West Swan River	A	Swan-Hibbing	S007-154	none	-	-	-	-	47.29779	-92.94978
Bug Creek	A	Toimi Uplands	S005-766	09LS052	7	4	+4	+12	47.11152	-92.34998
South Branch Whiteface R	A	Toimi Uplands	S005-769	09LS057	7	4	+2	-10	47.25218	-92.07922
South Branch Whiteface R	A	Toimi Uplands	S005-754	97LS019	6	3	+20 / +29	+20 / +21	47.28425	-92.09270
Partridge River	B	LU_Partridge	S004-595	09LS105	5	3	+28	+8	47.51862	-92.11485
Partridge River	B	LU_Partridge	S002-596	none	-	-	-	-	47.51409	-92.09502
Mud Hen Creek	B	Makinen Lakes	S005-070	09LS090	5	1	+19 / +14	+24 / +15 / +10	47.35765	-92.47113
Mud Hen Creek	B	Makinen Lakes	S007-034	09LS091	6	4	+21	+15	47.35012	-92.42005
Trib to St. Louis R	B	MDWLANDS	S005-758	09LS011	6	4	+20	-2	46.87372	-92.88340
Stoney Brook	B	MDWLANDS	S004-594	09LS016	5	3	+22 / +3	-9 / -3	46.85945	-92.60568
Hay Creek	B	NSMH	S005-942	97LS108	11	8	+24	-4	46.73556	-92.35518
Trib to Midway River	B	NSMH	S005-863	97LS112	11	8	+5	2	46.76356	-92.29600
Embarrass River	B	NU_EMB	S001-680	09LS100	7	4	-19 *	-5	47.67483	-92.05300
West Swan River	B	Swan-Hibbing	S005-757	98NF115	5	4	+19 / +16 / + 9	+3	47.24967	-92.83213
Whiteface River	B	Toimi Uplands	S005-768	09LS056	5	3	+18	+17	47.27245	-92.20257
Whiteface River	B	Toimi Uplands	S000-984	98LS046	5	3	+30 / +20	+15 / +12	47.14816	-92.59651
St. Louis River	C	MDWLANDS	S000-285	97LS027 / 09LS038	4		+29 / +31 / +21	+2 / +35 / +40 /+16	47.30292	-92.65753
Embarrass River	C	NU_EMB	S005-751	09LS095	5	4	+34	+23	47.40555	-92.40242
West Two River	C	W Two McQuade	S004-601	09LS073	5	3	+24 / +18	-2	47.34012	-92.68305
Partridge River	C	LU_Partridge	S005-752	09LS102 / 09LS114	5	3	+23 / -15	+18	47.51365	-92.18962


Editor
Table Of Contents
Layers
Grouping
A
B
C
eda_surfacewater_stations
STATION_TYPE
BIOLOGICAL
STREAM
delta_waterquality_stations sele
streamAuidsCurrent selection
impaired_2014_streams_draft se
SLR_watershed_zones
Sheet1__CU
Duluth Urban Trout Streams
Glacial Lake Superior Region
Laurentian Uplands - Partridg
Makinen Lakes
Meadowlands Floodwood Pe
Mille Lacs - North Shore High
Nashwauk Uplands - Embarra
Swan River - Hibbing
Toimi Uplands - Whiteface Hi
Virginia Mesabi Range
West Two - McQuade Morain
Minnesota composite aerial ph
Minnesota composite aerial
Minnesota Composite Ima

Group A

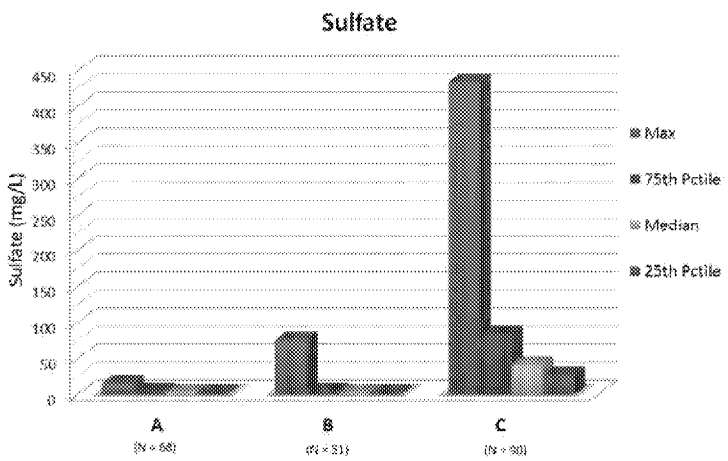
				MAX			MEDIAN			MIN
Parameter	N	Mean	SD	100%	95%	75%	50%	25%	5%	0%
Conductivity (µmhos/cm)	212	140	83	355	324	171	111	80	54	36
pH	216	7.42	0.38	8.37	8.09	7.68	7.40	7.20	6.85	6.10
TSS	137	4.3	2.9	20.0	8.8	5.7	3.5	2.3	1.0	0.4
Total Ammonia	149	0.05	0.06	0.56	0.11	0.06	0.04	0.02	0.01	0.00
NO2 + NO3	135	0.18	0.23	0.84	0.64	0.36	0.06	0.01	0.00	0.00
Total Phosphorous	148	0.035	0.027	0.230	0.075	0.039	0.030	0.022	0.013	0.001
Turbidity	109	4.4	2.5	17.4	8.1	5.8	3.8	2.9	1.8	0.8
Alkalinity	27	44.9	25.1	145.0	69.7	48.0	40.0	29.0	16.4	13.0
Sulfate	68	3.9	3.1	15.0	11.7	5.0	3.0	2.2	1.2	1.0

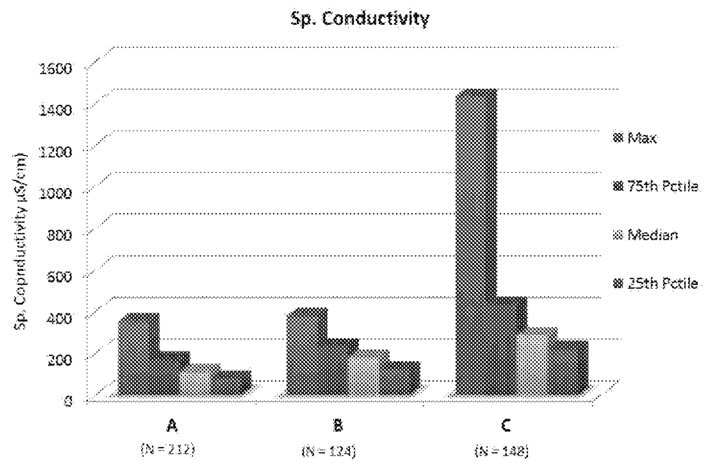
Group B

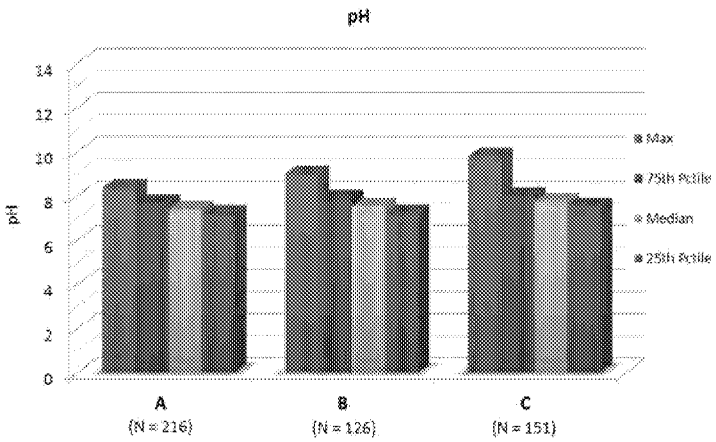
				MAX			MEDIAN			MIN
Parameter	N	Mean	SD	100%	95%	75%	50%	25%	5%	0%
Conductivity (µmhos/cm)	124	187	78	380	326	233	180	123	66	25
pH	126	7.53	0.53	9.00	8.28	7.90	7.54	7.21	6.50	6.23
TSS	64	6.3	12.7	98.0	15.9	5.8	3.2	2.0	1.0	0.5
Total Ammonia	30	0.062	0.093	0.390	0.281	0.050	0.024	0.016	0.010	0.009
NO2 + NO3	41	0.1	0.4	2.8	0.3	0.1	0.1	0.0	0.0	0.0
Total Phosphorous	46	0.037	0.018	0.101	0.072	0.043	0.037	0.029	0.010	0.001
Turbidity	73	5.8	3.8	17.7	13.2	7.0	5.0	3.0	2.0	1.3
Alkalinity	13	76.8	34.2	130.0	130.0	100.0	76.8	34.2	23.2	30.0
Sulfate	51	6.9	12.3	76.0	26.8	5.0	2.7	2.1	1.3	1.0

Group C

				MAX			MEDIAN			MIN
Parameter	N	Mean	SD	100%	95%	75%	50%	25%	5%	0%
Conductivity (µmhos/cm)	148	344	223	1433	556	433	287	222	109	6
pH	151	7.73	0.49	9.80	8.22	8	7.75	7.55	6.9	6.28
TSS	106	7.7	13.3	120	17	8	4	2.1	0.83	0.50
Total Ammonia	88	0.25	0.83	7.8	0.27	0.20	0.20	0.02	0.01	0.01
NO2 + NO3	79	0.16	0.17	0.77	0.33	0.21	0.11	0.03	0.00	0.00
Total Phosphorous	108	0.06	0.05	0.27	0.12	0.08	0.040	0.02	0.01	0.00
Turbidity	88	5.5	3.6	24.0	9.4	6.6	4.3	3.5	2.3	1.4
Alkalinity	36	78.7	33.8	180.0	115.0	92.0	82.5	53.8	28.3	25.0
Sulfate	90	72.7	77.9	434.0	190.1	83.5	41.5	27.0	15.8	2.3


Sulfate
Sulfate (mg/L)
450
400
350
300
250
200
150
100
50
0
Max
75th Pctile
Median
25th Pctile
A
(N = 68)
B
(N = 31)
C
(N = 98)


Sp. Conductivity
Sp. Conductivity µS/cm)
1600
1400
1200
1000
800
600
400
200
0
Max
75th Pctile
Median
25th Pctile
A
(N = 212)
B
(N = 124)
C
(N = 148)


pH
pH
14
12
10
8
6
4
2
0
Max
75th Pctile
Median
25th Pctile
A
(N = 216)
B
(N = 126)
C
(N = 151)

Listed Impaired Waters

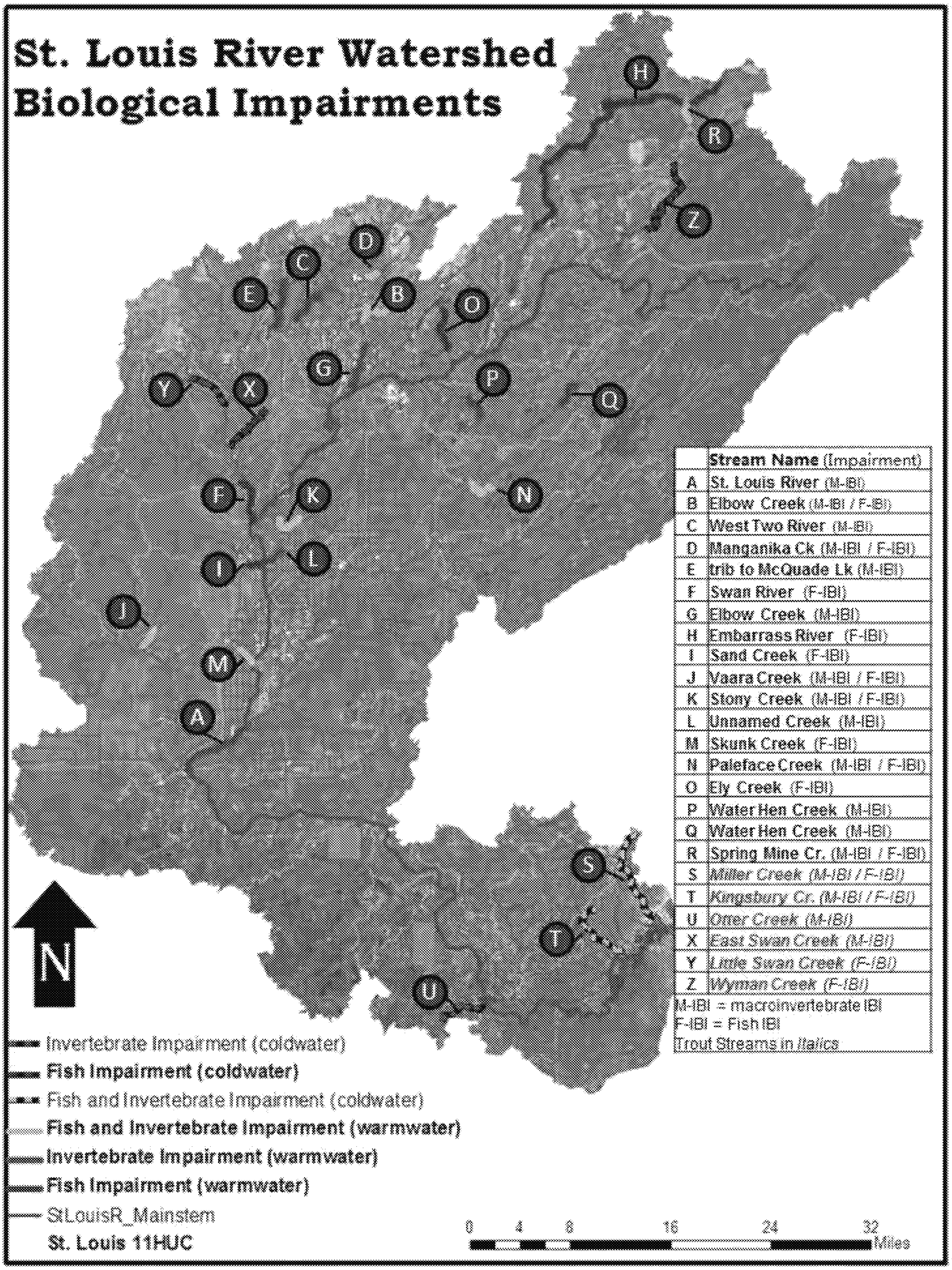
In 2009, the Minnesota Pollution Control Agency (MPCA) began an intensive watershed monitoring effort of the St. Louis River watershed's surface waters. Using the data collected during this effort, aquatic life assessments were completed for 75 stream and river segments, or assessment units (AUIDs) in the spring of 2011. These assessments were carried out in compliance with the federal Clean Water Act (CWA), which requires states to monitor and assess waterbodies for various criteria related to aquatic life and recreation. A complete summary of these assessments can be found in the St. Louis River Watershed Monitoring and Assessment Report (Anderson et al., 2012). Streams were assessed for a variety of water quality parameters and biological indicators (fish and aquatic macroinverterbrates). This report deals specifically with streams that were identified as impaired using fish and macroinvertebrate data.

Of the 75 AUIDs assessed for aquatic life, 24 (32%) were ultimately listed as "impaired waters" for failing to meet established IBI criteria for fish and/or aquatic macroinvertebrates. The impaired streams are listed in table BLANK, and their locations displayed on a map of the watershed in figure BLANK. Generally, the biological impairments in the SLRW are located on first and second order headwaters streams, although several impaired segments were identified on larger river systems, including the Swan River, Embarrass River, and a short section of the St. Louis River mainstem near Floodwood, MN.

Specific information related to each of these impairments will be presented in section BLANK. Fish and macroinvertebrate IBI scores, a discussion of biological metric results and symptoms of impairment, and stressor identification data will be presented in detail in that section of this report.

Stream Name	Stream Order *	Drainage Area *	AUID	Impairment	Fish Class **	Macroinvertebrate Class **	
Kingsbury Creek	2	7.1	04010201-626	F-IBI / M-IBI	11	8	Duluth Urbar
Miller Creek	2	8.0	04010201-512	F-IBI / M-IBI	11	8	Duluth Urbar
Wyman Creek	2	10.2	04010201-942	F-IBI	11	8	Laurentian U
Paleface Creek	2	29.5	04010201-A24	F-IBI / M-IBI	7	4	Makinen Lak
Water Hen Creek	2	15.9	04010201-A35	M-IBI	6	4	Makinen Lak
Water Hen River	3	68.5	04010201-A31	M-IBI	5	4	Makinen Lak
Little Swan Creek	2	21.1	04010201-891	F-IBI	11	8	Meadowland
Sand Creek	2	64.0	04010201-607	F-IBI	5	3, 4	Meadowland
Skunk Creek	2	15.0	04010201-A18	F-IBI / M-IBI	6	4	Meadowland
St Louis River	5	1,936.4	04010201-508	M-IBI	4	1	Meadowland
Stony Creek	2	21.5	04010201-963	F-IBI / M-IBI	6, 7	4	Meadowland
Vaara Creek	2	26.8	04010201-623	F-IBI / M-IBI	7	4	Meadowland
Unnamed Trib to St. Louis R.	1	4.8	04010201-A17	M-IBI	6	4	Meadowland
Otter Creek	3	39.7	04010201-629	M-IBI	11	8	Mille Lacs - N

Ely Creek	2	15.5	04010201-A26	F-IBI	6	4	Nashwauk Up
Embarrass River	2, 3	115.1	04010201-579	F-IBI	5, 7	4	Nashwauk Up
Spring Mine Creek	2	4.4	04010201-A42	F-IBI / M-IBI	6	4	Nashwauk Up
East Swan Creek	2	7.1	04010201-888	M-IBI	11	8	Swan River -
Swan River	4	244.3	04010201-557	F-IBI	5	4	Swan River -
Elbow Creek	1	3.2	04010201-518	F-IBI / M-IBI	6	4	Virginia Mesa
Elbow Creek	2	12.0	04010201-570	M-IBI	6	4	Virginia Mesa
Mangankika Creek	1	5.7	04010201-548	F-IBI / M-IBI	6	4	Virginia Mesa
McQuade Creek	3	17.5	04010201-551	M-IBI	6	3, 4	West Two - M
West Two River	3	33.5	04010201-535	M-IBI	6	4	West Two - M


St. Louis River Watershed
Biological Impairments
H
R
Z
D
C
E
B
O
G
P
Y
X
Q
F
K
N
I
L
J
M
A
S
T
U
N
Stream Name (Impairment)
A St. Louis River (M-IBI)
B Elbow Creek (M-IBI / F-IBI)
C West Two River (M-IBI)
D Manganika Ck (M-IBI / F-IBI)
E trib to McQuade Lk (M-IBI)
F Swan River (F-IBI)
G Elbow Creek (M-IBI)
H Embarrass River (F-IBI)
I Sand Creek (F-IBI)
J Vaara Creek (M-IBI / F-IBI)
K Stony Creek (M-IBI / F-IBI)
L Unnamed Creek (M-IBI)
M Skunk Creek (F-IBI)
N Paleface Creek (M-IBI / F-IBI)
O Ely Creek (F-IBI)
P Water Hen Creek (M-IBI)
Q Water Hen Creek (M-IBI)
R Spring Mine Cr. (M-IBI / F-IBI)
S Miller Creek (M-IBI / F-IBI)
T Kingsbury Cr. (M-IBI / F-IBI)
U Otter Creek (M-IBI)
X East Swan Creek (M-IBI)
Y Little Swan Creek (F-IBI)
Z Wyman Creek (F-IBI)
M-IBI = macroinvertebrate IBI
F-IBI = Fish IBI
Trout Streams in Italics
Invertebrate Impairment (coldwater)
Fish Impairment (coldwater)
Fish and Invertebrate Impairment (coldwater)
Fish and Invertebrate Impairment (warmwater)
Invertebrate Impairment (warmwater)
Fish Impairment (warmwater)
StLouisR_Mainstem
St. Louis 11HUC
0
4
8
16
24
32
Miles

Specifics of Impairment – Problem Metrics

The indices of biological integrity (IBI) used by MPCA measure a selection of attributes related to the diversity and types of species present, including feeding, reproduction, tolerance to human disturbance, abundance, and condition. The metrics used in each IBI vary depending on the size (drainage area) of the stream, geographical location, and its designated use classification (e.g. warmwater vs. coldwater stream).

Class #	Class_Name	Fish IBI Threshold	Upper CL*	Lower CL*
11	Northern Coldwater	35	45	25
4	Northern Rivers	38	47	29
5	Northern Streams	47	56	38
6	Northern Headwaters	42	58	26
7	Low Gradient	42	52	32

** "CL" denotes confidence limit for IBI threshold, which is often considered during assessment decisions*

While overall IBI scores a good tool for evaluating biological integrity or "health" of streams on a large scale, the individual metric scores can provide an in-depth look into the components of a fish or invertebrate community that are contributing to high or low IBI scores. Metric scores are evaluated further in this section to further investigate the nature of the biological impairments in the SLRW.

Fish Impairments
Class 11 – Northern Coldwater

Streams classified as "northern coldwater" include all designated trout streams in the northern half of Minnesota. In the most recent round of assessments conducted for SLRW streams, 15 of the stations were located on coldwater streams. Five out of the fifteen (33%) sites sampled recorded IBI scores below the impairment threshold.

Class 6 -- Northern Headwaters Streams

The "Northern Headwaters" fish IBI class stations are located on moderate to high gradient warm and coolwater streams with watershed areas of less than 50 mi^2. In the SLRW, there are 6 streams of this class with fish IBI impairments. A number of these streams originate from headwaters areas that have been altered significantly by mining land uses. Several of the other headwaters streams with fish IBI impairments are located in the expansive Meadowlands-Sax-Sim peat swamp, a region of the watershed that has been altered by extensive ditch networks and peat mining. The vast peat bog and wetland areas may also be naturally limiting to fish and invertebrate populations in these streams. These potential stressors will be covered in full in section BLANK.

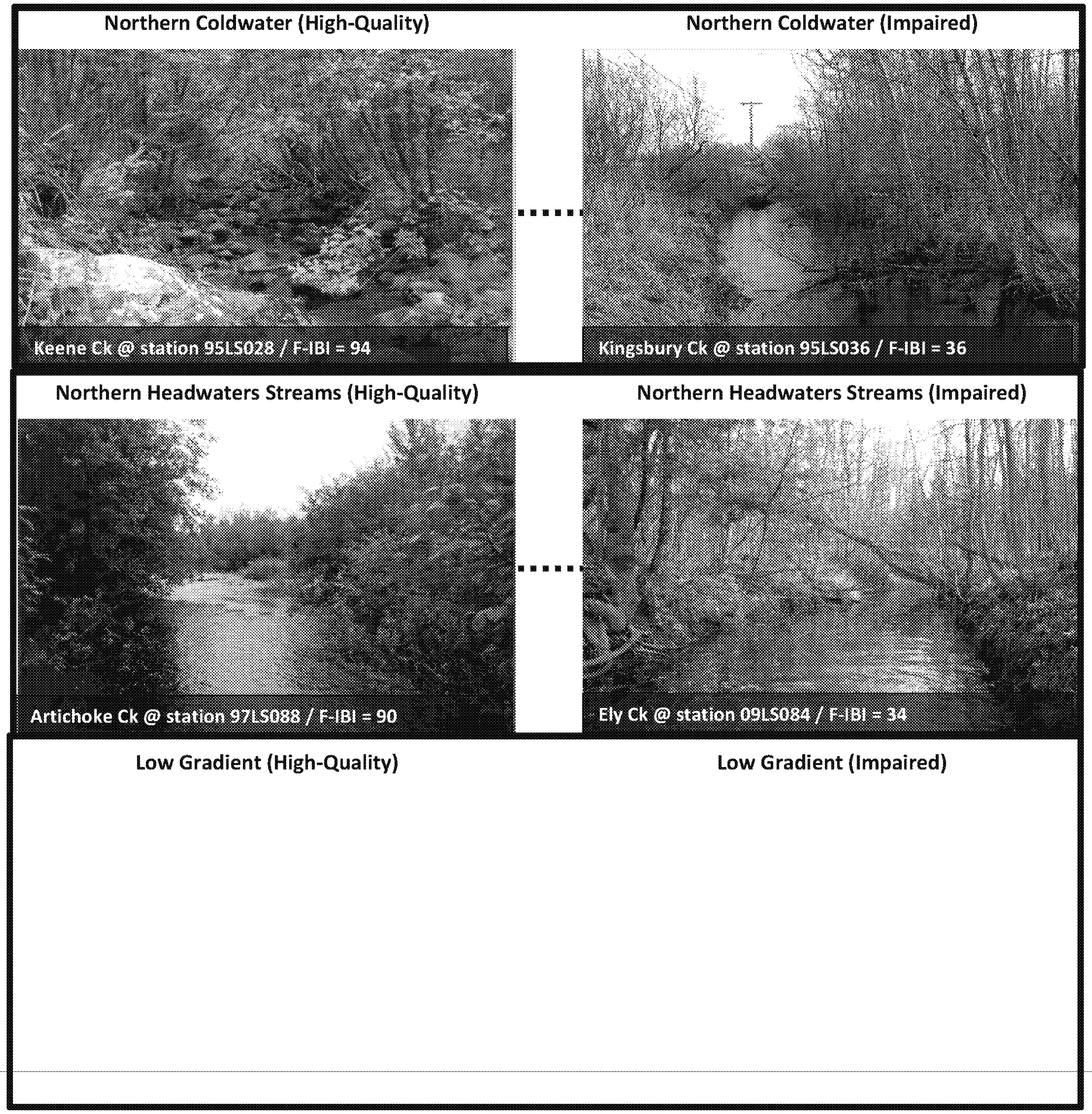
Class 5 – Northern Streams

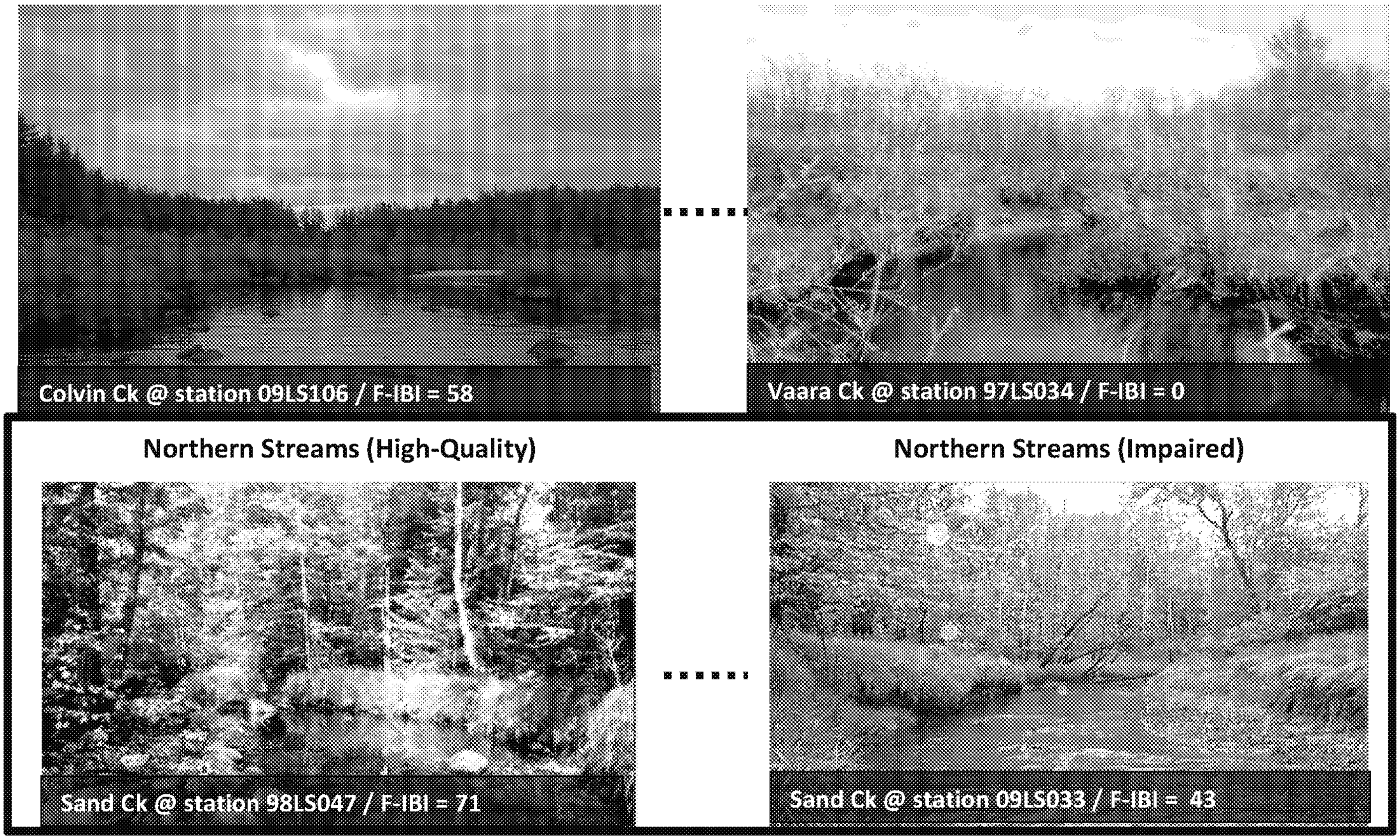
The "Northern Streams" IBI class includes warm and coolwater streams with drainage areas between 50 to 500 mi^2. The fish communities at streams in this IBI class were generally found to be in good to excellent condition based on the most recent monitoring results. Sand Creek, a second-order stream near the town of Toivola, MN, is the only stream of this class to be listed as impaired for fish IBI.

Sand Creek emerges from an expansive peat bog at its headwaters, and as a result, the surface water feeding the creek is heavily tannin stained and low in alkalinity. Dissolved oxygen concentrations also somewhat limited in portions of the creek due to wetland influence. The impaired reach of Sand Creek supports very few sensitive fish species, and is dominated by species that are serial spawners (spawn several times annually) and reach sexual maturity at an early age. The specific stressors impacting fish communities in the Sand Creek watershed will be further explored in later sections of this report.

Class 7 – Low Gradient

"Low Gradient" fish IBI stations are found on stream reaches with a watershed area less than 50 mi^2 and a gradient less than 0.5 m/km. Secondary characteristics are also used to classify a stream as low gradient even if the stream slope is greater than 0.5 m/km. These include; a lack of riffle habitat, low streamflow velocity, dominance of fine-grained substrates, and a riparian community dominated by wetland vegetation. A total of 17 low gradient sites were assessed during the most recent review of SLRW biological data; 7 out of the 17 stations (41%) scored below the IBI impairment threshold. Three stream segments were listed as impaired waters based on these results; Upper Embarrass River, Paleface Creek, and Vaara Creek





Macroinvertebrate Results

Intro

ColdNorth Class

The "Northern Coldwater Streams" macroinvertebrate IBI class is representative of coldwater streams located in the Northern portions of Minnesota. During the most recent assessment of the SLRW, a total of 14 sites of this IBI class were evaluated, and nearly half (43%) of these stations produced results that scored below the impairment threshold. Ultimately, three streams in the watershed were listed as impaired for failing to meet IBI criteria for this stream class; Kingsbury Creek, Miller Creek, Otter Creek, and East Swan Creek (see figure BLANK). Kingsbury Creek and Miller Creek are also listed as impaired for low fish IBI results.

Metric results for impaired and high-quality sites of this IBI class are shown in figure BLANK.

Northern Streams Glide-Pool Class

Monitoring stations classified as "Northern Streams Glide-Pool" (NSGP) are located on small to medium rivers (watershed areas less than 500 mi^2). Typical conditions found at stations of this IBI class include slow current velocity, lower gradient, and habitat features dominated by pool and glides. High velocity, shallow riffle features and deep runs are rare habitat types at NSGP stations.

The NSGP stream class is well-represented in the SLRW, with a total of 50 stations from this class being used for the most recent macroinvertebrate assessments in the SLRW. Of these 50 stations, 24 scored below the impairment threshold (48%). However, many of the stations scoring below the impairment threshold were not below that target by a large margin and were within the lower confidence limit range. In all, eleven stream segments were listed as impaired for failing to meet M-IBI standards in the NSGP IBI class.

Northern Streams Riffle-Run Class

The "Northern Streams Riffle-Run" IBI class stations are located on small to medium rivers (watershed area less than 500 mi^2) with prominent riffle-run habitats throughout the reach. Streams of this class are generally higher gradient than streams of the NSGP IBI class. A total of 31 stations from the NSRR class were used to assess macroinvertebrate biological integrity during the most recent assessment. Slightly over 28% of the NRSS stations sampled produced IBI scores below the impairment threshold, although half of these lower scoring sites fell within the lower confidence limit and do appear to be severely degraded.

Elbow Creek, a second order stream near Forbes, MN, and an unnamed tributary to McQuade Lake ("McQuade Creek") are the only two streams from the NRSS IBI class to be listed as impaired for failing to meet the M-IBI standard. Each of the impaired stations on these streams was sampled two times (fall 2009 & fall 2011), and there is a fair amount of variability in the metric results between sampling visits. Overall IBI scores for both streams improved during the 2011 monitoring visit, with the impaired site on McQuade Creek scoring narrowly above the impairment threshold. The 2011 data was not considered during the assessment of these streams, but will be evaluated in this report in the context of biological symptoms and stressor identification.

Both streams have low "climber" taxa richness compared to high-quality NRSS stations in the SLRW. Climber taxa are often found living and feeding on aquatic plants or plant debris in streams. Emergent and submergent aquatic vegetation was observed at these locations during habitat assessments, however, the abundance and diversity of species present was limited. These two impaired streams also share low scores in three metrics related to the number of predator, odonata (dragonflies), and plectoptera (stoneflies) taxa. Many species of Plecoptera and Odonata are predators, preying upon other organisms for their food source.

Northern Forest Rivers Class

The "Northern Forest Rivers" IBI class applies to monitoring sites located in northern Minnesota with watershed areas of at least 500 mi^2. In the SLRW basin, only the St. Louis River and Whiteface River have monitoring stations that meet these criteria. During the most recent assessment, monitoring data from 9 stations were assessed within this IBI class, 8 of those stations being located on the mainstem of the St. Louis River. IBI scores below the impairment threshold were recorded at 3 stations, two on the St. Louis River, and one on the Whiteface River. The St. Louis River was listed as impaired for macroinvertebrate IBI based on the sampling results.

Symptoms of Impairment by Watershed Zone

One of the purposes of establishing watershed zones was to observe trends in biological data at the sub-watershed or regional scale. Tables BLANK and BLANK (need to insert tables) provide a summary of fish and invertebrate metric results by stream and watershed zone, with the intent of revealing any commonalities among impaired streams in various zones of the SLRW.

Background on Stressors / Identification of Candidate Causes

Water Quality

(Intro to Water Quality section 1-2 paragraphs)

A broad, high-level review of water quality data is presented in this section with the goal of summarizing current conditions and developing list of candidate stressors related to water quality parameters. Available water quality data from impaired reaches were reviewed and summarized for each impaired stream in the SLRW and compared to Minnesota water quality standards where applicable. For parameters without associated water quality standards, data from a selection of high quality reference streams were used for comparison. Water quality parameters were broken in to seven categories for further evaluation and screening candidate causes for impairment (table BLANK).

Given that the goal of this step is to develop a large list of candidate causes for further analysis, a conservative approach was used in eliminating water quality parameters as a candidate stressor. If results for a given parameter were inconclusive, it was advanced as a candidate cause for further analysis.

Water Quality Categories Evaluated
Water Temperature
Dissolved Oxygen (DO)
pH
Ionic Strength / Alkalinity
Nutrients
Turbidity and Suspended Sediment
Toxicity (Metals, Nutrients, and other agents)

Water Temperature

Fish and macroinvertebrate species are often restricted in their distribution based on the temperature ranges observed within streams, rivers, and lakes. Although adaptations have taken place that allow certain species to live within the colder and warmer extremes of natural waters, very few taxa are able to cope with very high water temperatures. Species that occupy streams with a narrow temperature range are referred to as *stenothermal*, while those that thrive over a wide temperature range are called *eurythermal*. Species common to trout streams in the SLRW, such as brook trout and mottled sculpin, are considered coldwater stenotherms, because they are unable to survive when water temperatures become elevated.

Water temperature has the most potential to act as a stressor to aquatic life during the cold and warm extremes of the year. The northern latitude of the SLRW renders the biota of the region vulnerable to both of these critical periods. Winter monitoring of water temperatures and below-ice conditions are challenging. Although occasional winter measurements and observations were taken, they were not a major part of this monitoring effort. As a result, most of the focus on water temperature as a stressor will be placed on summer extremes.

Water temperature stressors will be a focus primarily for those watershed zones that contained impaired coldwater streams (Duluth Urban Coldwater, North Shore Highlands, Meadowlands Floodwood Peat Bog, Swan River-Hibbing, and Laurentian Uplands-Partridge Headwaters).

Warmwater & Coolwater Streams of the SLRW

Seventy-five percent (18 of 24) of the impaired stream reaches in the SLRW are considered warmwater or coolwater streams. These streams have likely never supported brook trout or other coldwater species, and are currently managed as non-trout bearing streams. The specific temperature thresholds that separate cold, cool, and warmwater stream classes are not defined by rule in Minnesota, and will tend to vary by region. Fish and macroinvertebrate species inhabiting these streams are generally able to tolerate wider temperature ranges and higher maximum temperatures. Most warmwater fishes, including esocids (pikes) and cyprinids (minnows) have upper temperature tolerance limits near 30 C.

Instantaneous temperature readings from impaired warm and coolwater streams are included in Appendix BLANK. The highest temperature recorded was 27.2 C (Stoney Brook, MF-PB Zone), which is still within the suitable range for supporting warmwater fish species. Impaired streams in the SR-H and WTM watershed zones show lower maximum temperatures and noticeably narrower ranges between minimum and maximum temperatures. This is likely due to the influence of groundwater and mine pit dewatering to these streams.

Based on the available data for warm and coolwater streams in the SLRW, elevated water temperatures are an unlikely cause of impairment and can be eliminated as a candidate cause. The specific streams for which temperature has been eliminated as a stressor can be found in Appendix BLANK.

Coldwater Streams of the SLRW

Instantaneous temperature readings from the months of July and August were compiled for the six impaired stream segments on designated trout streams in the SLRW. Continuous temperature loggers were also deployed in these streams, and the data collected during these continuos monitoring periods were also considered in identifying streams with potential impacts related to water temperature. The results are displayed in box-plots by watershed zone in figure BLANK. Stream temperatures were found to be in the range of thermal stress in all watershed zones of the SLRW. Temperatures considered lethal to brook trout were not exceeded by any of the instantaneous measurements, although streams in the DUC watershed zone (Kingsbury Creek and Miller Creek) had temperatures that approached this threshold.

This screening level assessment of stream temperature data shows that elevated stream temperatures are a candidate cause for impairment in all watershed zones that contain coldwater streams. This candidate cause will be further evaluated with continuous temperature data and biological data in section BLANK of this report.

Dissolved Oxygen and Eutrophication

Dissolved oxygen (DO) refers to the concentration of oxygen gas within the water column. Low or highly fluctuating concentrations of DO can have detrimental effects on many fish and macroinvertebrate species ((Davis, 1975); (Nebeker, 1991)). DO concentrations change seasonally and daily in response to shifts in ambient air and water temperature, along with various chemical, physical, and biological processes within the water column. If DO concentrations become limited or fluctuate dramatically, aerobic aquatic life can experience reduced growth or fatality (Allan, 1995). Many species of fish avoid areas where DO concentrations are below five mg/L (Raleigh, 1986). For more detailed information on DO go to the EPA Caddis webpage following this link. (U.S.EPA)

The class 2B (warmwater) water quality standard for DO in Minnesota is 5 mg/L as a daily minimum, while the class 2A (coldwater) water quality standard for DO in Minnesota is 7 mg/L as a daily minimum. Additional stipulations have been recently added to this standard that require most of the data to be collected during times where sub-optimal dissolved oxygen concentrations typically occur. For more information on this dissolved oxygen standard, refer to the Guidance Manual for Assessing the Quality of Minnesota Surface Waters (MPCA, 2009).

Nutrients and Eutrophication

Nutrient enrichment (particularly total phosphorous), chlorophyll-a (Chl-a) concentrations, and measures of biological oxygen demand (BOD) are all factors in the dissolved oxygen regime of streams and rivers. MPCA has developed nutrient criteria for Minnesota rivers (not yet official state rules) with target concentrations for total phosphorous and several related stressor effects linked to excess nutrients, including high diurnal DO flux (DO flux), Chlorophyl-a (Chl-a), and biological oxygen demand (BOD). The entirety of the SLRW falls within the "North" River Nutrient Region. The targets associated with this River Nutrient Region are listed in table BLANK.

Table BLANK:

	Nutrient	Stressor		
Region	TP µg/L	Chl-a µg/L	DO flux mg/L	BOD_5 mg/L
North	55	<10	≤4.0	≤1.5
Central	100	<20	≤4.5	≤2.0
South	150	<40	≤5.0	<3.5

In most cases, nutrients are not proximate stressors for aquatic communities. Although certain forms of nitrogen [i.e., unionized ammonia (NH_3), nitrite (NO_2^-) and, in some cases, nitrate (NO_3^-)] may be toxic, these effects are considered separate candidate causes for impairment. Nutrients have indirect adverse effects on aquatic communities through their effects on primary production, the growth and accumulation of plant and algal biomass, and the species composition of algae (i.e., phytoplankton in lakes or periphyton in streams) and other plant assemblages (Dodds and Welch, 2000) (Text from EPA CADDIS website).

TP concentrations exceeding the regional target of 0.055 mg/L are observed in biota-impaired streams within nearly every watershed zone of the SLRW -- with the only exception being Wyman Creek in the LU-P zone. However, median and 75th percentile TP concentrations for most of these impaired streams are below the regional target. In many cases, the elevated TP results may be limited to high flow events during snowmelt or large summer rain events. Two watershed zones had median TP concentrations above the target for the North nutrient region, Swan River-Hibbing and Virginia Range Streams (table BLANK). Special attention will be given to the role that eutrophication plays in the DO regime of streams in these watershed zones.

<u>Chl-a</u>

Limited chl-a data are available for biota-impaired streams in the SLRW. Data from the late 1970's and 1980's are available for East Swan Creek, Elbow Creek, and Manganika Creek, but chl-a data on streams were not collected as part of the recent SLRW assessment process and stressor identification study. The lone chl-a result from Manganika Creek (213 µg/L), collected in August of 1986, is over 20 times higher than the North region target of <10 µg/L. Chl-a results from East Swan Creek also exceeded 10 µg/L in over 40% of the samples taken (4 of 9), but the maximum concentration of 16 µg/L was much lower than what was observed in Manganika Creek. The two available Chl-a results for Elbow Creek are both below 2 µg/L, but these samples were collected upstream of Elbow Lake, which often experiences large algae blooms.

Biological oxygen demand (BOD) measures the amount of oxygen consumed by microorganisms in decomposing organic matter in streams.

Candidate Cause Screening: Dissolved Oxygen

Instantaneous dissolved oxygen data were plotted by SLRW watershed zone to identify areas where low dissolved oxygen may be a candidate cause of biological impairments. The data used for this screening assessment were collected exclusively from stream segments with biological impairments. A separate analysis was performed that included only data collected during the months of July, August, and September, as this tends to be the time of year when critically low dissolved concentrations are often observed.

Dissolved oxygen concentrations below state water quality standards were recorded in all watershed zones of the SLRW. As a result, dissolved oxygen will be further evaluated as a candidate cause for impairment for all of the impaired streams in the SLRW.

Total phosphorous (TP) concentrations are elevated in many watershed zones with biological impairments (figure BLANK). The TP criteria of 0.055 mg/L was exceeded by at least one stream in all of the watershed zones, with the exception of the LU-Partridge (Wyman Creek).

{Add section for DO Flux}

pH

The pH of water is a measure of the degree of its acid or alkaline reaction. Freshwaters can vary widely in pH due to natural and anthropogenic inputs. Extreme pH values, generally those below 5 or above 9, are harmful to most organisms (Allan, 1995). Different species flourish within different ranges of pH, with the optima for most aquatic organisms falling between pH 6.5 - 8.0. The applicable pH standard for most Class 2 waters is a minimum of 6.5 and a maximum of 8.5, based on the more stringent of the standards for the applicable multiple beneficial uses. pH values that are outside the range of the standard because of natural causes are not considered violations.

Due to the natural diversity of the watershed and a variety of anthropogenic disturbances, streams of the SLRW display a wide range of pH values. The swamps and peat bogs of the MDW-PB watershed zone contribute large amounts of humic acid to streams of that region, resulting in brown or black stained waters and pH values between 4 and 7. Streams of the MKL and NU-EMB watershed zones are also generally acidic due to the presence of wetlands and bogs. The combination of more alkaline geology and soils along with the industrial and municipal discharges results in pH values between 7 and 9 throughout most of the other watershed zones.

Candidate Cause Screening: pH

The pH values of several impaired streams in the SLRW are exceeding state water quality standards. Low pH values in the MDW-PB, MKL, and NU-EMB watershed zones may be limiting biological diversity and contributing to biological impairments. Elevated pH concentrations (>8.5) in the VIR watershed zone are observed regularly on Manganika Creek in the VIR watershed zone, and may be contributing to biological impairments in that stream. Therefore, pH will be further evaluated as a candidate cause of impairment in all of these watershed zones.

Ionic Strength, Sulfate, Chloride, and Total Dissolved Solids

Ionic strength is the concentration of ionic charge in solution. Ionic strength varies naturally across aquatic ecosystems, and aquatic organisms generally prefer waters with specific ionic strength ranges. Aquatic organisms maintain a careful water and ion balance, and can become stressed by an increase in ion concentrations (SETAC, 2004). Calcium, sodium, and magnesium are all necessary for aquatic health, and occur naturally, but imbalances can be toxic (SETAC, 2004). Measurements of electrical conductivity, salinity, and total dissolved solids (TDS) are often used to represent the ionic strength of water, which generally increases with increasing ion content. For the purposes of this report, conductivity values will be presented as specific conductivity in µS/cm.

<u>**Sources and Pathways**</u>

Urbanization

Increases in specific conductivity are among the most consistently documented water quality changes associated with urbanization. For example, Kaushal et al. (2005) examined salinization of suburban and urban streams in Maryland. They found that **chloride concentrations exceeded thresholds for sensitive freshwater taxa at sites with greater than 40% impervious cover** (Fig 23). In winter, chloride concentrations reached peaks of **nearly 25% the concentration of seawater**, and concentrations remained up to 100 times higher than at forested and agricultural non- impervious sites throughout the year.

This increase in dissolved solutes in urban streams has been attributed to several sources, including:

- Road salt and other deicing agents (in northern regions)
- Point source discharges (e.g., WWTP and industrial effluents)
- Leaky sewer and septic systems
- Concrete weathering

Some studies have shown that urbanization-associated changes in conductivity are related to shifts in biotic assemblages. For example:

Roy et al. (2003) found that **specific conductance was a significant predictor of invertebrate responses to urbanization**, negatively related to total invertebrate richness, EPT richness, total invertebrate density, and several benthic invertebrate indices.

Helms et al. (2009) found that **streams with high concentrations of total dissolved solids were dominated by sunfish-based fish assemblages**.

However, in many cases it is believed that conductivity is a general indicator of overall urban impact, rather than a direct cause of observed biotic effects.

Industrial Wastewater

Municipal Wastewater

Effects on Aquatic Life

There is debate as to the exact mechanisms responsible for toxicity associated with ionic strength. Toxicity due to ionic strength could result from disruption of organisms' osmotic regulation processes, decreases in bioavailability of essential elements, increases in availability of heavy metal ions, increases in particularly harmful ions, changes in ionic composition, absence of chemical constituents that offset impacts of harmful ions, a combination of the above, or other as yet unknown mechanisms. In some instances (perhaps the majority), increased ionic strength causes shifts in community composition rather than mortality. Thus, specific conductivity, salinity, and TDS levels may be associated with biological impairment and yet be below mortality thresholds.

Biological effects of conductivity are often difficult to quantify. Increased ionic strength can cause community shifts favoring ion tolerant taxa and an increase in ion tolerant life stages, but it is difficult to separate the role of ionic strength in this shift from influence of confounding stressors. With increases in ionic strength, macroinvertebrate taxa richness (particularly Ephemeroptera sp.) have been found to decrease (Piscart et al., 2005). Echols et. al (2009) observed a reduction in EPT abundance as conductivity values increased. A study of Minnesota biological data and stressor linkages found that sites with conductivities higher than 1,000 µS/cm rarely meet the biological thresholds for general use streams (MBI, 2012). A statewide review of specific conductance values and

Applicable Water Quality Standards

Minnesota does not currently have a water quality standard for specific conductance that is based on protecting aquatic organisms. A standard of 1,000 µS/cm is incorporated into state rule for class 4A waters, which are protected for crop irrigation purposes.

{Insert Ecoregion values}

SLRW Data Discussion

Specific conductivity values vary widely among the streams of the SLRW due to natural factors (e.g. local geology, wetlands and lakes, groundwater) and anthropogenic land-uses that have altered the natural condition of surface and groundwater (e.g. mining, urbanization, wastewater treatment). In areas of the SLRW that are relatively unaffected by mining, urbanization, or agriculture, stream conductivity values ranged from 36 to 380 µS/cm and were generally below 230 µS/cm (see section BLANK). In general, conductivity values exceeding 500 µS/cm are limited to the watershed zones with mining and/or urban land-uses (figure BLANK).

Specific conductivity data from impaired stream reaches in the SLRW are shown in box-plot form by watershed zone in figure BLANK. Also displayed on this box-plot graph are conductivity data from the reference stream groupings that were discussed in section BLANK. The available data shows conductivity values that are well above background levels in several SLRW watershed zones, most notably the Duluth Urban Coldwater, Swan River-Hibbing, West Two-McQuade, Virgina Iron Range, and Nashwauk Uplands-Embarrass River zones. Conductivity readings greater than 2,000 µS/cm have been observed in Manganika Creek (VIR watershed Zone) during baseflow, and values exceeding than 1,000 µS/cm occur regularly during lower streamflow periods in Spring Mine Creek (NU-EMB), East Swan Creek (SR-HIB).

The impaired streams within the Makinen Lakes and Meadowlands Floodwood Peat Bog exhibit low specific conductivity values in comparison to other streams of the SLRW. Several of these streams rarely have conductivity levels above 150 µS/cm and are often well below 100 µS/cm. Stream-dwelling organisms require water of some minimal ionic concentration, and some research indicates that waters low in ionic concentration can lead to limited abundance and diversity of aquatic flora and fauna (Allan, 1995).

Candidate Cause Screening: Ionic Strength (Specific Conductance)

Most streams that support healthy fish and macroinvertebrate assemblages have a conductivity range between 150 to 500 µS/cm (US EPA website). It should be noted that several streams in the SLRW continue to support relatively healthy fish and macroinvertebrate assemblages despite regularly-occurring conductivity readings > 500 µS/cm. Examples include the lower West Two River and several reaches of the mainstem of the St. Louis River.

Watershed zones with impaired streams that regularly exceed a specific conductivity of 500 µS/cm will be further evaluated for stressors related to elevated ionic strength. These include; Duluth Urban Coldwater (DUC), Swan River – Hibbing (SR-HIB), West Two-McQuade Moraine (WT-M), Virginia Iron Range (VIR), and the Nashwauk Uplands – Embarrass (NU-EMB). The single conductivity reading in the Makinen Lakes watershed zone is an extreme outlier for streams in that region of the watershed. Therefore, ionic strength is not considered a stressor in that watershed zone.

Streams exhibiting specific conductivity levels less than 100 µS/cm during low flow periods (July through September) will be further evaluated to determine if low ionic strength is contributing to biological impairment. Watershed zones that will be evaluated for low ionic strength as a stressor include; Nashwauk Uplands-Embarrass (NU-EMB), Meadowlands Floodwood Peat Bog (MDW-FB), and Makinen Lakes (MKL).

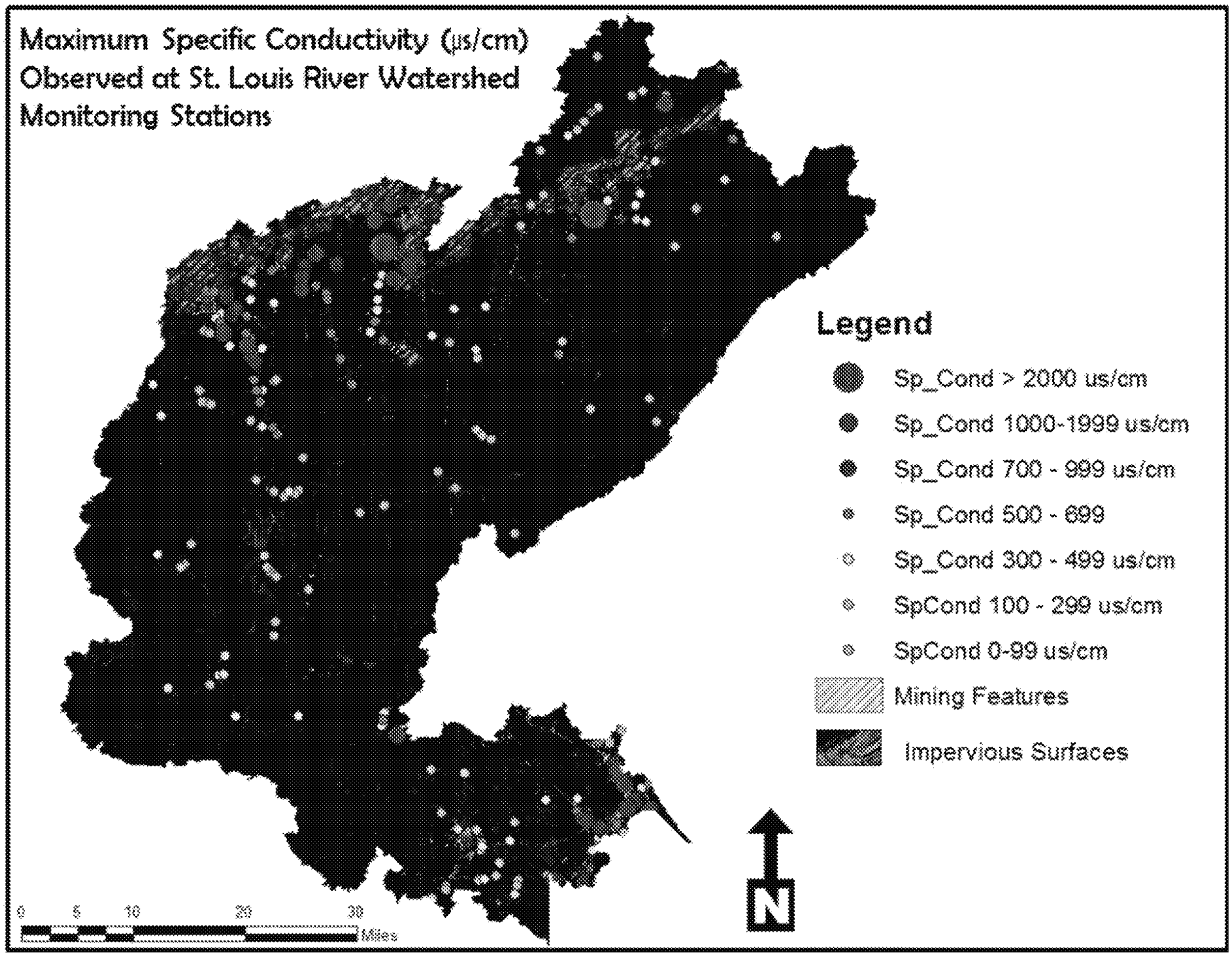


Figure BLANK:

Sulfate

Sulfate is a common compound generally found in low concentrations in natural streams. Natural sources of sulfate in surface waters include the decomposition of leaves, atmospheric deposition, or the weathering of certain geologic formations including pyrite (iron disulfide) and gypsum (calcium sulfate) (DEP Pennsylvania,). A variety of anthropogenic activities on the landscape can result in elevated SO_4^- concentrations, including wastewaters from mining or industrial processes, and runoff from agricultural areas.

Elevated sulfate concentrations in surface waters of the St. Louis River watershed have been widely documented. An excerpt from a recent paper by Berndt and Bavin (2012) offers a good summary of sulfate sources and interaction with other elements on the land and in the water column:

> **From Berndt and Bavin, 2012:**
>
> *It has long been known that mining activities on the Iron Range result in release of sulfate (SO4) to the St. Louis River (Moyle and Kenyon, 1947; Maderak, 1963; Peterson, 1979; Lindgren et al.,2006; Berndt and Bavin, 2009). Most of this SO4 is released from the oxidation of minor sulfide minerals that are exposed to oxygen in waste rock piles and tailings placed on land. Although sulfide oxidation sometimes creates acidic conditions in other ore mining districts, acid produced in this region appears to be fully neutralized by dissolution of carbonate minerals that are abundant in the iron formation. Thus, in addition to elevated SO_4, these waters tend to have high alkalinity ($HCO3^-$) and hardness (mostly Mg^{++} and Ca^{++}) compared to waters from surrounding watersheds without mines (Berndt and Bavin, 2009). SO4¼ concentrations for major streams in the area rarely exceed 100 mg L_1 SO4¼ but waters sampled from pits close to the highest sulfide-bearing waste rock piles can have SO4¼ concentrations of 1000 mg L_1 and above.*

Toxicity Testing and Water Quality Standards for Sulfate

Over the past decade, there has been a growing interest in studying the toxicity of sulfate in aquatic ecosystems. Sulfate toxicity has been evaluated in recent years through laboratory testing of various organisms (Elphick et al., 2010; Soucek 2004, 2006, 2007; Soucek and Kennedy, 2005) and in some cases by various state agencies looking to further understand sulfate related stressors (Rankin 2003,2004) or develop water quality standards for sulfate (Buchwalter, 2013; DEP Pennsylvania; Iowa DNR, 2009). Table BLANK provides a summary of these investigations and resulting water quality standards or benchmarks for sulfate concentrations to protecting various forms of aquatic life.

{INSERT SULFATE WQS TABLE}

Given the lack of an aquatic-life based sulfate standard in Minnesota, a combination of the guidelines and standards shown in table BLANK will be used to evaluate sulfate as a candidate stressor in the SLRW. Several of the standards and guidelines included in this report are the focus of ongoing research. Taking this into consideration, some caution will be used in terms of diagnosing sulfate as a stressor without applicable Minnesota water quality standards.

The lowest toxicity value for sulfate included in table BLANK is a chronic criterion of 75 mg/L for soft-water (10-40 mg/L) as reported in Elphick (2010). The biota-impaired streams of the SLRW with hardness within or near the range of 10-40 mg/L for portions of the year carry relatively low concentrations of sulfate (n = 56, max = 57.7 mg/L; min = > 1 mg/L; median = 6.8 mg/L). This includes all impaired streams in the MDW-PB, NSH-ML, and ML watershed zones. Based on the available data, sulfate is eliminated as a candidate cause for impairment in these watershed zones.

The next most-protective sulfate toxicity benchmark cited in table BLANK is a chronic criterion value of 124 mg/L SO4 (Buchwalter, 2010). This criterion is not adjusted based on ambient water hardness values or chloride concentrations, and can be considered one of the more "protective" standards listed in table BLANK. This criterion will be applied to the remaining SLRW biota-impaired streams that are not considered to have "soft" water (hardness 10-40 mg/L) for the purposes of selecting sulfate as a candidate cause of impairment. Sulfate concentrations from five biota-impaired streams exceeded 124 mg/L in at least one sample. These include, Spring Mine Creek (NU-EMB), Elbow Creek (VIR), Manganika Creek (VIR), West Two River (WTM), and McQuade Creek (WTM). Sulfate toxicity is considered a candidate cause in these streams and will be further evaluated in section BLANK.

Chloride

The negative effects of elevated chloride concentrations on aquatic life have been well documented, especially in urban areas. Chloride enters the environment in small amounts through the dissolution of mineral salts, but human uses of chloride salts result in the greatest input to surface waters. Of greatest importance are sources from municipal and industrial discharges containing salt wastes from water softening or process water, and stormwater sources associated with use of chlorides in road de-icing salts, agricultural runoff (livestock waste and fertilizer) and produced water from oil and gas wells. The use of road salt and de-icing products has increased considerably in the United States since 1950, putting more urban streams at risk for this stressor (Kostick, 1993).

The recommended national criteria and current Minnesota water quality standard for chloride are established at a chronic value of 230 mg chloride/liter, implemented as a four-day average concentration and acute (maximum concentration) of 860 mg chloride / liter, implemented as a one-day average concentration.

Suspended Sediment and Turbidity

Increases in suspended sediment and turbidity within aquatic systems are now considered one of the greatest causes of water quality and biological impairment in the United States (U.S. EPA, 2003). Although sediment delivery and transport are an important natural process in all stream systems, sediment imbalance (either excess sediment or lack of sediment) can result in the loss of habitat and/or direct physical or physiological harm to aquatic organisms. As described in a review by Waters (1995), excess suspended sediments cause harm to aquatic life through two major pathways: (1) direct, physical effects on biota (e.g. abrasion of gills, suppression of photosynthesis, avoidance behaviors); and (2) indirect effects (e.g. loss of visibility, increase in sediment oxygen demand).

Applicable Water Quality Standards

Since the late 1960's, MPCA has used a turbidity standard of 25 NTU as a means of addressing aquatic life use impacts resulting from increased suspended particles (sediment, algae, etc.). Although many rivers remain listed as impaired for turbidity (including several streams in the SLRW), the agency is moving towards a water quality standard based on TSS criteria. Unlike turbidity, TSS is a "concentration-based" parameter, which facilities the development of load allocations during the TMDL process.

In the fall of 2010, MPCA released draft TSS standards for public comment (Markus, 2010). The new TSS criteria are stratified by geographic region and stream class (e.g. coldwater, warmwater) to account for differences in natural background conditions and biological sensitivity. The draft TSS standard for warmwater and coolwater streams of the SLRW is 15 mg/L. Coldwater streams have a slightly lower impairment threshold value of 10 mg/L. An impairment listing may occur when these values are exceeded in more than 10% of samples during the months of April through September.

For the purposes of Stressor Identification, TSS results will be relied upon to evaluate the effects of suspended solids and turbidity on fish and macroinvertebrate populations. The available turbidity data for the watershed exists in several different units of measurement, and at times the equipment used to measure turbidity can produce erroneous results if instrumentation is not calibrated adequately. TSS results are available for the watershed from state-certified laboratories and the existing data covers a much larger spatial and temporal scale in the watershed.

Data Discussion

Reference or background TSS concentrations in the St. Louis River watershed are relatively low compared to other regions of Minnesota. McCollor and Heiskary (1993) observed that the 75th percentile value for a set of minimally impacted streams of the Northern Lakes and Forests ecoregion was 6.4 mg/L. The 75th percentile TSS concentration from the selection of SLR reference streams discussed in Appendix BLANK ranged from 5.7 mg/L to 10.5 mg/L depending on the grouping used (Table BLANK).

Table BLANK:

				MAX			MEDIAN			MIN
Parameter	N	Mean	SD	100%	95%	75%	50%	25%	5%	0%
TSS (Reference Group A)	137	4.3	2.9	20.0	8.8	5.7	3.5	2.3	1.0	0.4
TSS (Reference Group B)	64	6.3	12.7	98.0	15.9	5.8	3.2	2.0	1.0	0.5
TSS (Reference Group C)	76	9.7	15.3	120.0	31.3	10.5	5.6	2.3	0.8	0.5

Available TSS data for the impaired stream reaches were compiled and graphed by watershed zone to identify areas where elevated TSS may be a candidate cause of biological impairments. Five of the ten watershed zones contain coldwater streams, and were therefore evaluated using the coldwater TSS standard (noted by the “c” designation in figure BLANK).

Impaired streams of the DUC and SR-HIB watershed zones show the highest TSS concentrations among the streams analyzed (figure BLANK). These watershed zones include two urban trout streams, Miller Creek and Kingsbury Creek (DUC Zone) as well as East Swan Creek (also trout stream) and the Swan River on the Iron Range (SR-HIB Zone). TSS concentrations in both of these streams frequently exceed the warmwater and coldwater water quality standard, particularly during spring snowmelt and large rain events. Elevated TSS is considered a candidate cause for impairment in these watershed zones and will be further evaluated. Wyman Creek, the lone impaired stream in the Laurentian Uplands-Partridge River watershed zone, exceeded the 10 mg/L coldwater TSS standard which applies to that stream (figure BLANK). TSS will also be further evaluated as a candidate cause in the LU-Partridge watershed zone.

TSS concentrations in streams of the MF-PB watershed zone are slightly elevated and occasionally exceed water quality targets for coldwater and warmwater streams. The majority of the TSS results between 10 and 30 mg/L in this watershed zone were observed on Little Swan Creek, a coldwater tributary of the East Swan River. Over 30% (8 of 25 samples) of the TSS results from Little Swan Creek exceed the 10 mg/L TSS standard for coldwater streams. Sand Creek and Stony Creek exceeded the 15 mg/L warmwater TSS standard during several spring and summer monitoring events. Based on the review of available data for this watershed zone, TSS is considered a candidate cause for impairment and will be further evaluated for linkages to biota impairments in this region.

Otter Creek in the ML-NSH watershed zone narrowly exceeded the 10 mg/L TSS standard during a 2012 snowmelt sampling event, however, this stream generally exhibits low TSS concentrations. Summer baseflow samples collected in Otter Creek ranged from <1 mg/L to 3 mg/L. TSS is not considered a candidate cause for impairment in Otter Creek and will not be evaluated as a stressor in the ML-NSH watershed zone.

Elevated TSS concentrations are rare in the Makinen Lakes, West-Two McQuade, and Nashwauk Uplands-Embarrass watershed zones. Ely Creek, a tributary to the St. Louis River in the NU-EMB watershed is the only exception, with TSS concentrations as high as 30 mg/L and an exceedance rate of 21% (3 of 14 samples). TSS is considered a candidate cause for impairment on Ely Creek, therefore the NU-EMB watershed zone will be further evaluated for TSS.

TSS will be further evaluated as a candidate cause for impairment in the VIR watershed zone due to high concentrations in Manganika Creek. TSS concentrations in Manganika Creek are highest during the summer low flow periods and are at least partially due to algae blooms originating in Manganika Lake upstream from the monitoring station. The other impaired stream in this watershed zone, Elbow Creek, did not show any signs of elevated TSS concentrations.

Nitrate Toxicity

Nitrate (NO_3) and nitrite (NO_2) forms of nitrogen are components of the natural nitrogen cycle in aquatic ecosystems. NO_3 anions are naturally present in soil and water, and are routinely converted to NO_2 by microorganisms as part of the nitrification and denitrification processes involved in the nitrogen cycle. Nitrogen cycling in the environment results in nitrogenous compounds such as ammonia denitrifying into the more stable and conservative nitrate ion (NO3).

Elevated nitrate concentrations in surface water have been linked to a variety of sources and pathways. Anthropogenic alterations of the landscape, namely an increase in agricultural land-use, have increased ambient nitrate concentrations in some watersheds to levels that can be toxic to some fish and macroinvertebrates (Lewis and Morris, 1986; Jensen, 2003). In addition to agricultural sources, elevated NO_2 and NO_3 concentrations have also been linked to effluent from facilities producing metals, dyes, and celluloids (Kimlinger, 1975) and sewage (Alleman, 1978).

The intake of nitrite and nitrate by aquatic organisms has been shown to convert oxygen-carrying pigments into forms that are unable to carry oxygen, thus inducing a toxic effect on fish and invertebrates (Grabda et al, 1974; Kropouva et al, 2005). Certain species of caddisflies, amphipods, and salmonid fishes seem to be the most sensitive to nitrate toxicity (Camargo and Alonso, 2006). Nitrate toxicity to freshwater aquatic life is dependent on concentration and exposure time, as well as the overall sensitivity of the organism(s) in question. Comargo et al (2005) cited a maximum level of 2 mg/L nitrate-N as appropriate for protecting the most sensitive freshwater species, although the in the same review paper, the authors also offered a recommendation of NO3 concentrations under 10 mg/L as protective of several sensitive fish and aquatic invertebrate taxa.

In Minnesota, natural inputs of nitrate to surface waters vary by geographic location. However, when nitrate concentrations in surface water samples from "reference" areas (i.e., areas with relatively little human impact) are compared to samples from areas of greater human impact, the reference areas exhibit much lower nitrate concentrations (Monson and Preimesberger, 2010). Nitrate concentrations under "reference" conditions in Minnesota are typically below 1 mg/L (Heiskary and Wilson, 2005). A statistical breakdown of nitrate results from 25 reference sites in the SLRW is shown below in table BLANK. Aside from a single result of 2.8 mg/L from the Partridge River near Hoyt Lakes, maximum nitrate values were below 1.0 mg/L at all of these locations.

Table BLANK:

				MAX			MEDIAN			MIN
Parameter	N	Mean	SD	100%	95%	75%	50%	25%	5%	0%
TSS (Reference Group A)	135	0.18	0.23	0.84	0.64	0.36	0.06	0.01	0.00	0.00
TSS (Reference Group B)	41	0.1	0.4	2.8	0.3	0.1	0.1	0.0	0.0	0.0
TSS (Reference Group C)	49	0.2	0.2	0.8	0.6	0.2	0.1	0.0	0.0	0.0

SLRW Data Discussion

All available NO_2 + NO_3 (nitrate) data for biota-impaired stream reaches in the SLRW are shown in a box-plot graph by watershed zone in figure BLANK. Based on these data, elevated nitrate concentrations are clearly a candidate cause for impairment in the SR-HIB watershed zone. Nitrate concentrations are particularly high in East Swan Creek (up to 11 mg/L). Excluding results from East Swan Creek and Swan River (SR-HIB Watershed Zone), nitrate concentrations on all other impaired streams are below 2.0 mg/L, and 98% of the results (359 of 366) from these streams are below 1 mg/L. Elevated nitrate concentrations are not considered a candidate cause for impairment in any watershed zone other than SR-HIB.

Ammonia-N Toxicity

Ammonia (NH_3) is a common toxicant derived from wastes (Figure 1), fertilizers, and natural processes. Ammonia nitrogen includes both the ionized form (ammonium, NH_4^+) and the unionized form (ammonia, NH_3). An increase in pH favors formation of the more toxic unionized form (NH_3), while a decrease favors the ionized (NH_4^+) form. Temperature also affects the toxicity of ammonia to aquatic life. Ammonia is a common cause of fish kills, but the most common problems associated with ammonia relate to elevated concentrations affecting fish growth, gill condition, organ weights, and hematocrit (Milne et al. 2000). Exposure duration and frequency strongly influence the severity of effects (Milne et al. 2000) (Text taken from EPA CADDIS).

Ammonia in sediments typically results from bacterial decomposition of natural and anthropogenic organic matter that accumulates in sediment. Sediment microbiota mineralize organic nitrogen or (less commonly) produce ammonia by dissimilatory nitrate reduction. Ammonia is especially prevalent in anoxic sediments because nitrification (the oxidation of ammonia to nitrite [NO_2^-] and nitrate [NO_3^-]) is inhibited. Ammonia generated in sediment may be toxic to benthic or surface water biota (Lapota et al. 2000).

Ammonia also exerts a biochemical oxygen demand on receiving waters (referred to as nitrogenous biological oxygen demand or NBOD) because dissolved oxygen is consumed as bacteria and other microbes oxidize ammonia into nitrite and nitrate. The resulting dissolved oxygen reductions can decrease species diversity and even cause fish kills. Additionally, ammonia can lead to heavy plant growth (eutrophication) due to its nutrient properties (see the Nutrients module). Conversely, algae and macrophytes take up ammonia, thereby reducing aqueous concentrations.

Ionic strength: Tolerance to NH_3 can increase with an increase in ionic strength or salinity (Sampaio et al. 2002).

Sediments: Fine sediments tend to generate ammonia due to low oxygen levels and high organic matter.

{Add section when the database works}

Metals Toxicity

While some metals are essential as nutrients, all metals can be toxic at some level, and some metals are toxic in minute amounts. Impairments result when metals are biologically available at toxic concentrations affecting the survival, reproduction, and behavior of aquatic organisms. Metals that are commonly linked to toxic effects include arsenic, cadmium, chromium, copper, lead, inorganic mercury, nickel, selenium, and zinc. A list of anthropogenic sources of metals and common effects on water quality and biota are described in table BLANK. There are numerous sources in the SLRW that could contribute to increased concentrations of a variety of metals, including urban runoff, landfills, municipal and industrial point sources, and mining operations.

Trace metals with toxicity-based standards used in water quality assessments include ~~cadmium~~, chromium, ~~copper, lead~~, nickel, selenium and zinc. Mercury is discussed in the Chapter V, because it has a human health-based standard.

Table BLANK:

Sources and Activities

- Mines and smelters
- Firing ranges
- Municipal waste treatment outfalls
- Industrial point sources
- Urban runoff
- Landfills
- Junkyards

Site Evidence

- Blue, orange, or yellow precipitate in water
- Site data for metals
- Site chemistry favoring metals bioavailability

Biological Effects

- Kills of aquatic life
- Mucous streaming from gills
- Gill damage
- Blue stomachs (molybdenum)
- Spinal abnormalities (calcium analogs)
- Blackened tails
- Replacement of metals-sensitive species with tolerant species

Metal	CS	MS	FAV	CS	MS	FAV	Candidate Stressor / Watershed Zone
Aluminum	87 (Tox)	748 (Tox)	1,496 (Tox)	125 (Tox)	1,072 (Tox)	2,145 (Tox)	SR-HIB
Arsenic	2.0 (HH)	360 (HH)	720 (Tox)	53 (HH)	360 (HH)	720 (Tox)	None
Cadmium	Based on h2O Hardness Values (See appendix BLANK)						None
Chromium	Based on h2O Hardness Values (See appendix BLANK)						None
Copper	Based on h2O Hardness Values (See appendix BLANK)						DUC, SR-HIB
Lead	Based on h2O Hardness Values (See appendix BLANK)						DUC
Nickel	Based on h2O Hardness Values (See appendix BLANK)						
Zinc	Based on h2O Hardness Values (See appendix BLANK)						

Aluminum

Aluminum occurs ubiquitously in natural waters as a result of the weathering of aluminum-containing rocks and minerals, but concentrations in surface waters can be increased directly or indirectly by human activity through industrial and municipal discharges, surface run-off, and wet and dry atmospheric deposition (Eisenreich 1980). The use of alum (aluminum sulfate) as a flocculent in water treatment facilities typically leads to high aluminum concentrations in finished waters (DOI 1970; Letterman and Driscoll 1988; Miller et al. 1984a). Weathering of sulfide ores exposed to the atmosphere in inactive mines and tailings dumps can release large quantities of sulfuric acid and metals such as aluminum (Filipek et al. 1987).

The mobilization of aluminum is often episodic in nature, and is regularly associated with pH depressions (acidification) occurring during the spring snowmelt or with erosion from specific storm events (Campbell et al., 1992; Nelson and Campbell 1991; Rossland et al., 1990). At lower pH levels, the aluminum content significantly increases because of increased solubility of aluminum oxide and salts in acidic solutions. Higher aluminum concentrations have also been observed in waters with elevated humic acid content (Brusewitz, 1984). Therefore, streams located in peat-bog dominated regions of the SLRW may have naturally higher alumimun concentrations than streams with other land cover types. Dissolved organic matter (DOM) and sulfates in water may bind with Al and alter its bioavailablility. DOM can typically complex 50-70% of the dissolved Al in natural waters at pH 4.5 – 6.5, and the result is a decrease in the bioavailability of Al to aquatic organisms.

Aluminum toxicity has been studied extensively in fish, and to a lesser extent for aquatic macroinvertebrates. In aquatic systems, bioavailability and toxicity of aluminum is closely related to ambient pH. Aluminum is only sparingly soluble in the pH range that is found in most streams of the SLRW (6.0 to 8.5). At moderate pH (5.5-7.0), fish and invertebrates may be stressed due to aluminum adsorption onto gill surfaces and subsequent asphyxiation (Campbell,).

In general, aquatic invertebrates are less sensitive to aluminum toxicity than fish. The addition of 400-500 μg/L Al within a pH range of 4.0 – 4.3 had negligible effects on mortality in clams (Pisidium sp.), amphipods (Hyallela sp.), snails (Amnicola and Physella sp.), or insect larvae (Enallagma sp., Lepidostoma sp., or Pycnopsyche sp.). Similarly, additions of neither 350 μg/L nor 1,000 μg/L Al at the same pH range affected survivorship in larval benthic insects (Havas and Likens, 1985; Ormerod et al., 1987).

Water Quality Standard: Aluminum

The water quality standard for aluminum in is listed in table BLANK. Unlike other metals evaluated in this report, the standard for aluminum is not adjusted based on water hardness.

Candidate Cause Screening: Aluminum Toxicity

Aluminum data on biota-impaired streams in the SLRW are shown by watershed zone in figure BLANK. The plot is developed with very few data points, as Al data is somewhat limited for these streams.

Cadmium

Cadmium is a relatively rare element that is a minor nutrient for plants at low concentrations (Lane and Morel 2000; Lee et al. 1995; Price and Morel 1990), but is toxic to aquatic life at concentrations only slightly higher. Cadmium can enter the environment from various anthropogenic sources, such as by-products from zinc refining, coal combustion, mine wastes, electroplating processes, iron and steel production, pigments, fertilizers and pesticides (Hutton 1983; Pickering and Gast 1972).

The primary mechanism of cadmium toxicity, like other metals, is binding to fish gills and disrupting cation transport channels on the membranes of the gills. It is difficult to measure the toxic form of cadmium because it binds to numerous constituents that depend on site-specific water chemistry. Dissolved cadmium is considered the toxic form. Its bioavailability is primarily dependent on the calcium and magnesium concentrations in the water because these cations compete with the cadmium for binding sites (Monson and Monson, 2012).

Water Quality Standard: Cadmium

The water quality standards for cadmium are based on the hardness of the water being sampled. As hardness decreases, the cadmium thresholds for CS, MS, and FAV also decrease. The lowest hardness value observed among impaired streams in this study was 40 mg/L (Upper Embarrass River). At a hardness of 40 mg/L, the CS for cadmium is 0.55 μg/L.

Candidate Cause Screening: Cadmium Toxicity

Cadmium concentrations observed in the biota-impaired streams were nearly all below 0.1 μ/L (75 of 76 results; > 98%), with the only exception being a result of 0.91 μg/L on the Upper Embarrass River in July of 1977. Based on the hardness value at the time of this sample, a concentration of 0.91 μg/L exceeded the CS for cadmium (hardness = 52 mg/L, cadmium CS = 0.67 mg/L). However, the other 17 sampling results for cadmium at this monitoring station rest were all below 0.1 μg/L. It is very likely that the 0.91 μg/L result is the result of a short duration event or sampling error. Based on the available data, cadmium is not considered a candidate cause for impairment in any of the watershed zones.

Arsenic

Arsenic (As) is a relatively common element that occurs in air, water, soil, and all living tissues. Organisms are exposed to arsenic through numerous pathways, including atmospheric emissions from smelters, coal-fired power plants, herbicide sprays, water contaminated by mine tailings, and natural mineralization processes. Aresenic bioavailability and toxic properties are significantly modified by numerous biological and abiotic factors that include the physical and chemical forms of arsenic tested, the route of administration, the dose, and the species of animal. Arsenic is bioconcentrated by organisms, but not biomagnified in the food chain.

Water Quality Standard: Arsenic

The water quality standard for aluminum in is listed in table BLANK. The CS and MS listed for class 2A and 2B streams is based on human-health, while the FAV listed for both stream classes is based on toxicity data.

Candidate Cause Screening: Arsenic Toxicity
Arsenic concentrations in biota-impaired streams were generally below the 2.0 µg/L human-health based chronic water quality standard for class 2A (coldwater) streams (figure BLANK). Data from all locations were significantly below the class 2B (warmwater) chronic standard. Relative to the other streams, slightly elevated As concentrations were observed in Manganika Creek (VIR watershed Zone) and a tributary to Wyman Creek originating from an abandoned mine pit. Although concentrations were elevated (5 – 11 µg/L), they were significantly below levels that can be considered harmful to aquatic life. Based on the available data, toxicity from arsenic is not considered a candidate cause in any of the watershed zones with biota impairments.

Copper

Copper is a common natural element that is found in geologic deposits that include cadmium and zinc as well. According to EPA (2007), naturally occurring copper ranges from 0.20 to 30 µg/L in freshwater (Monson and Monson, 2010). Copper is associated with various anthropogenic activities, including discharges from mining, leather processing, metal fabrication, and electrical equipment production. Copper is found in municipal wastewater because of the corrosion of copper pipes. Copper sulfate is a common algicide to treat nuisance algal blooms in lakes and ponds (Cooke and Welch 2005), but can also toxic to the zooplankton that graze on the algae.

Copper is an essential nutrient at very low levels, but as it increases in concentration it becomes toxic to animal and plant life by binding to key organic molecules (ligands) and interfering with waste removal from blood or hemolymph. Specific biological effects of copper on fish at non-toxic levels make it useful to model the causal pathway between copper and impairments for fish and invertebrates separately.

Copper interferes with olfaction in fish. Fish can detect copper at relatively low levels, changing behavior to avoid low concentrations. Copper is often used to chase fish in to nets due to the strength of avoidance behavior. This change in behavior reduces feeding, inhibits thermoregulation, and ultimately results in lower growth rates. Copper intoxication can also result in etiological shifts that reduce the growth, reproduction, and survival of fish. Fish eggs are particularly sensitive to copper, with little or no survival of eggs at copper levels that are not harmful to adults.

Finally, because different macroinvertebrates exhibit varying copper tolerances, copper can influence macroinvertebrate species composition as well as directly impacting growth, reproduction, survival, and life cycle phenology. In general, benthic invertebrates are most sensitive to copper accumulation in sediments (Ye et al., 2007).

Water Quality Standard: Copper

Copper toxicity to aquatic life varies with its bio-availability, which is mediated primarily by pH and hardness. Minnesota's current water quality standard for copper is based on water hardness and is discussed in greater detail in Appendix BLANK.

Candidate Cause Screening: Copper Toxicity
Available copper data for biota-impaired streams are plotted by watershed zone in figure BLANK.

Lead

Lead is a non-essential element for plant, animal, and human nutrition, but is ubiquitous in our environment. Aquatic environments receive led through precipitation, fallout of lead dust, street runoff, and both industrial and municipal wastewater discharges (U.S. EPA, 1976). Generally, the solubility of lead in water decreases with increased alkalinity.

Invertebrate species show varying sensitivities to lead. Amphipods (scuds) were reported by Spehar, et al. (1978) to be more sensitive to lead than any other invertebrate thus far tested. Interestingly, this same relationship existed in longer exposures lasting up to 28 days in which the scud was far more sensitive to lead than a snail, cladoceran, chironomid, mayfly, stonefly, and caddisfly (Spehar, et al. 1978; Biesinger and Christensen, 1972; Anderson, et al. 1980; and Nehring, 1976).

Spinal deformities due to lead were noted in a life-cycle test of three generations of brook trout (Holcombe et al., 1976). The chronic values obtained by these investigators were 58 to 119 µg/L Pb (total) in water of hardness 44 mg/L as $CaCO_3$.

Water Quality Standard: Lead

The water quality standards for Pb toxicity are based on water hardness. As hardness decreases, the Pb thresholds for CS, MS, and FAV also decrease. The lowest hardness value observed among impaired streams in this study was 40 mg/L (Upper Embarrass River). At a hardness of 40 mg/L, the CS, MS, and FAV for lead are 5.57 µg/L, 7.48 µg/L, and 14.96 µg/L, respectively.

Candidate Cause Screening: Lead

Zinc

Zinc (Zn) is one of the most commonly occurring heavy metals in natural waters, and is an essential element for most plants and animals. The toxicity of Zn to aquatic life varies widely between species, and is modified by several ambient factors in streams, including water hardness, dissolved oxygen concentration, and temperature. Zinc is acutely toxic to select freshwater organisms at concentrations as low as 90 µg/L (Rabe and Sappington, 1970), and the lowest reported chronic effects documented are between 26 and 51 µg/L (Spehar 1976).

Water Quality Standard: Zinc

The water quality standards for Zn toxicity are based on water hardness. As hardness decreases, the Zn thresholds for CS, MS, and FAV also decrease. The lowest hardness value observed among impaired streams in this study was 40 mg/L (Upper Embarrass River). All other streams evaluated in this study have shown hardness values equal to or greater than 40 mg/L. At a hardness of 40 mg/L, the CS, MS, and FAV for lead are 48.77 µg/L, 53.84 µg/L, and 107.68 µg/L, respectively.

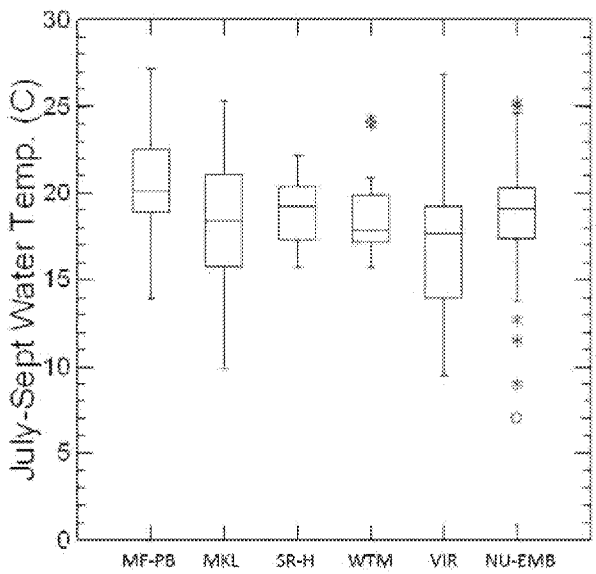
Candidate Cause Screening: Zinc

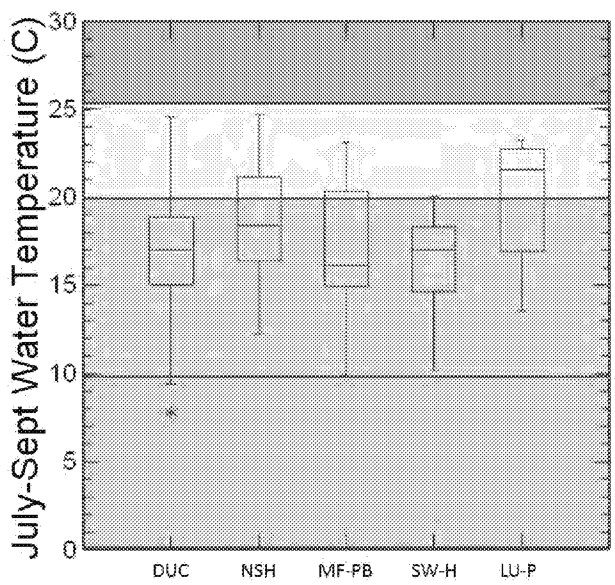
Monitoring results for Zn from biota-impaired streams of the SLRW are displayed in box-plots by watershed zone in figure BLANK. Nearly all of the results for Zn are well below the CS at a hardness of 40 mg/L (48.8 µg/L Zn), which represents the softest water sampled among the impaired streams. Zn concentration exceeded 48 µg/L in East Swan Creek (VIR watershed zone) during a single sampling event in August, 1979. However, water hardness is generally much higher in East Swan Creek, which increases the concentration at which Zn becomes toxic. At the time of sampling, hardness was 190 mg/L, which equates to a CS for Zn of 182.6 µg/L, nearly four times the observed Zn concentration.

Based on the available data, it does not appear that Zn toxicity is acting as a stressor in any of the biota-impaired streams.

Nickel, Chromium, and Selenium

Other trace metals that were evaluated as potential candidate stressors include nickel, chromium, and selenium. Sampling results for these metals are included in appendix BLANK. Concentrations of these trace metals were generally very low in the biota-impaired streams that were focused on as part of this stressor identification study.





Overview of Analysis Tools

- TIV's and logistic regression curves

-

Logistic regression curves have been developed by Sandberg (2014) to estimate the probability of a stream reach meeting the TSS standard based on fish assemblage data (see Appendix BLANK). These curves utilize taxa-specific tolerance indicator values (TIV) for various parameterThe curve in figure BLANK was developed using two categorical variables; (1) aggregate TIVs for biological monitornone of wtake into account species specific tolerance indicator values (TIV) for TSS and calculates

Evaluation of Candidate Stressors

Duluth Urban Trout Streams

The Duluth Urban Coldwater watershed zone contains two impaired coldwater streams, Miller Creek and Kingsbury Creek. Both of these urban trout streams are listed as impaired for failing to meet IBI criteria for fish and macroinvertebrates. Some of the potential stressors in that will be evaluated in this watershed zone include elevated water temperatures, altered hydrology, total suspended solids, chloride toxicity, lack of connectivity, and habitat degradation. Many of these potential stressors are likely linked to high density urban land-uses and/or natural background limitations due to the bedrock geology of the region.

Figure BLANK: Representative reaches of impaired coldwater streams in the Duluth Urban Coldwater watershed zone. (Left) Reach of Kingsbury Creek showing high gradient / bedrock geology nature of these streams. (Center) Impacts of 2012 flood Kingsbury Creek. (Right) Channelized portion of Miller Creek in high-density commercial area.

Common symptoms of macroinvertebrate impairment in this watershed zone include a lack of intolerant taxa, low POET (Plecoptera, Odonata, Ephemeroptera, and Trichoptera) taxa richness, and low scores in the Hilsenhoff Biotic Index (HBI), which is known to respond negatively to many types of disturbance, including organic pollution and thermal stress. The macroinvertebrate assemblages in Kingsbury and Miller Creeks contained a higher relative percentage of non-insect taxa, such as snails, scuds (amphipods), crayfish, and aquatic worms. Many of the non-insect macroinvertebrate taxa are more tolerant of stressors like low dissolved oxygen or benthic habitat degradation.

Both of these streams show a reduced number or lack of fish species that are considered "intolerant" or "sensitive" to disturbance in coldwater streams. Examples of these species observed in high-quality coldwater streams within the SLRW include brook trout (*Salvelinus fontinalis*), longnose dace (***Rhinichthys cataractae***), mottled sculpin (*Cottus bairdii*), and longnose sucker (***Catostomus catostomus***). Native brook trout, as well as non-native brown trout, were present at several monitoring stations on impaired reaches of Kingsbury Creek and Miller Creek during 2009 and 2012 sampling visits, but they accounted for a relatively low percentage of the overall population. Sampling results also indicate that many of the trout observed were the result of recent stocking efforts. Pioneer species such as blacknose dace, creek chub, and white sucker were typically dominant in these streams. High quality trout streams of smaller stream orders (1-3) typically have low taxa richness, and the species present are highly specialized to thrive in streams with colder water temperatures.

Fish IBI scores for Miller and Kingsbury Creek were also lower due to an abundance of omnivorous fish taxa. Omnivorous fish species are those that have the physiological ability (usually indicated by the presence of a long coiled gut and dark peritonium) to digest both plants and animals. They are able to utilize any available food resources, and their dominance within a fish community indicates an unstable food base. They are more tolerant of degradation than trophic specialists, because they can survive even if more sensitive food resources (e.g. benthic invertebrates) are reduced or eliminated, by switching to other, less sensitive, food resources. Coldwater obligate species such as trout and sculpin are trophic specialists relying on insect life (aquatic and terrestrial) and the predation of other fish for food.

Analsys of Candidate Stressors for Impaired Streams

Kingsbury Creek

Based on current and historical fisheries data, Kingsbury Creek is a marginal coldwater stream that relies on stocking to maintain a population of trout. Young –of-the-year (YOY) brook trout have never been observed n Kingsbury Creek since monitoring was initiated in 1968. Brown trout (YOY) were observed in 1993, and perhaps again in 2012 upstream of US HWY 2.

Temperature

Temperature data was collected at three MPCA biosites on Kingsbury Creek: 98LS003 upstream of the Proctor High School ball fields, 12LS004 upstream of Highway 2, and 12LS005 upstream of the Lake Superior Zoo. The logger at 12LS005 was swept away during the June 2012 flood and had to be replaced – therefore only August 2012 data is available at that site. Additionally, data was used from MN DNR loggers at five sites between 1998 and 2002. Only data between June 1 and August 31 were analyzed (when stream temperatures are most likely to exceed the stress threshold for coldwater obligate species).

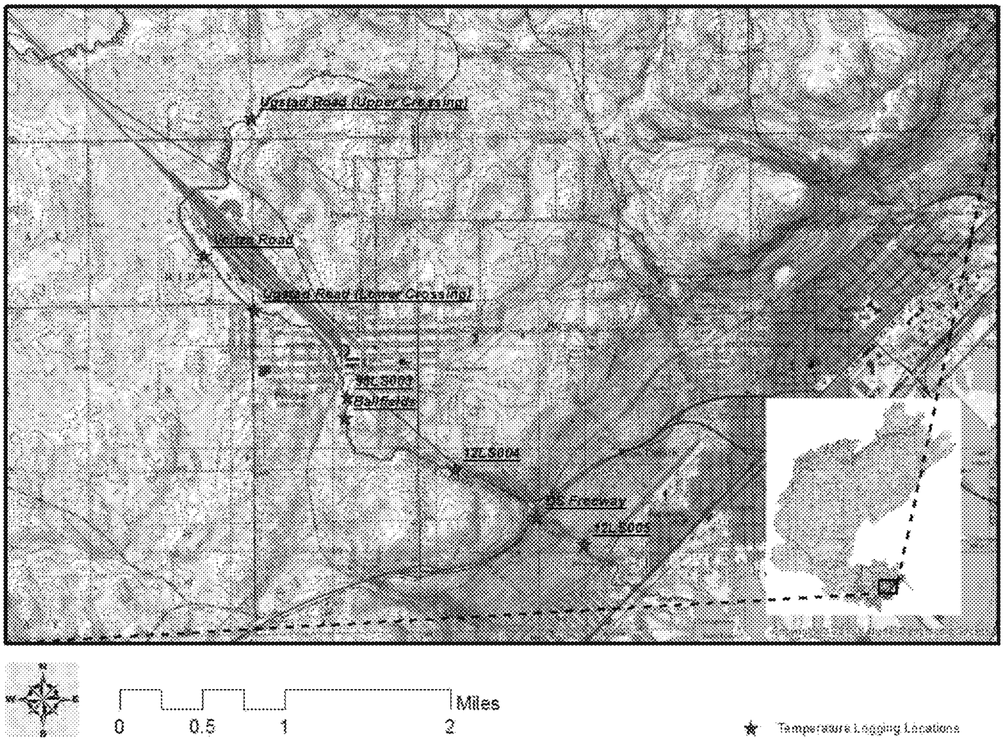


Figure X: HOBO logger locations on Kingsbury Creek

Late June to the middle of August seems to be the critical time in Kingsbury Creek for coldwater sensitive species like brook trout. Figure X shows that the average maximum daily temperature well exceeded the stress threshold of 68° F for the majority of that time period.

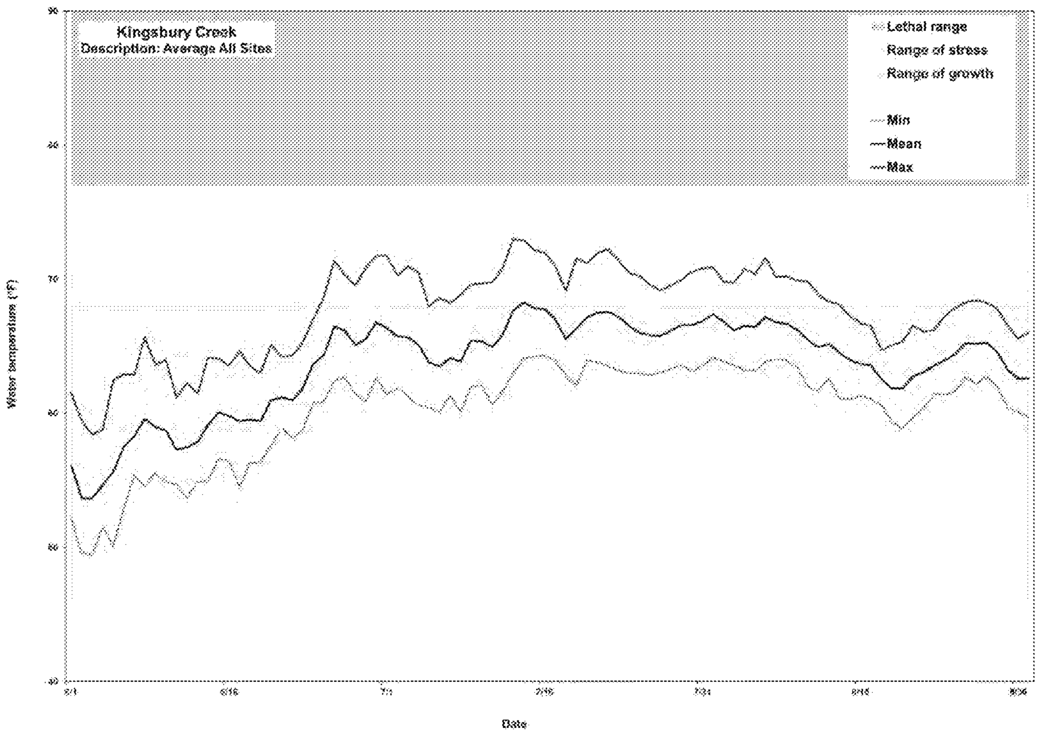


Figure X: Average daily minimum, mean, and maximum temperatures for all temperature loggers at all sites in Kingsbury Creek

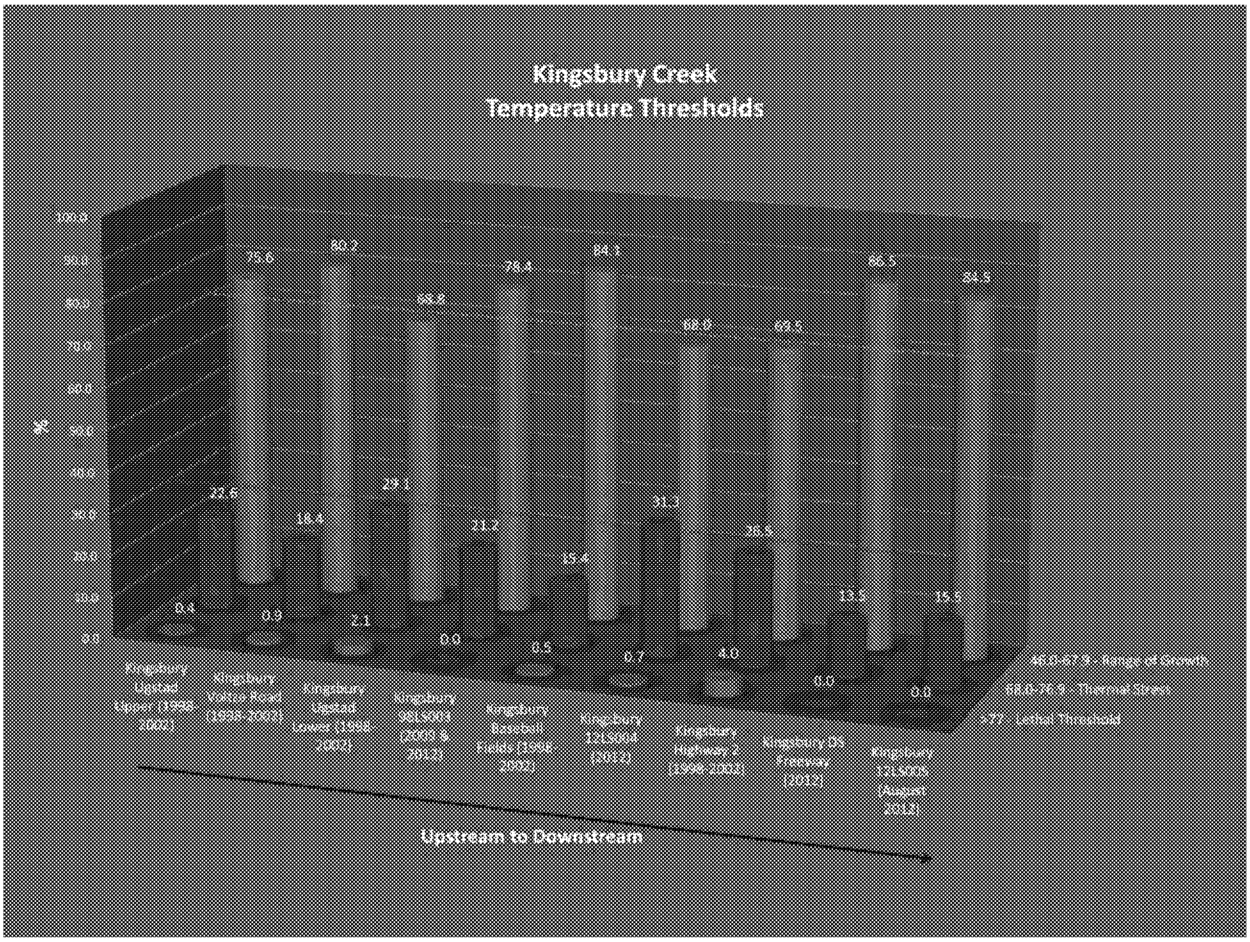


Figure X: Percentage of time spent in BKT growth, stress and lethal ranges

Figure X shows the spatial breakdown of the temperature data, which was evaluated using at least 70% of the time in growth temperature (46.0-67.9° F) as the indicator of whether or not BKT should be present based on water temperature alone. It is clear that at the majority of the Kingsbury Creek sites the water temperature was adequate for most coldwater species and was in the brook trout growth range at least 70% of the time. Three sites fell below 70% growth – Ugstad Road (Lower Crossing), 12LS004, and the DNR Highway 2 site (which is very close to 12LS004). The Ugstad Road and Highway 2 sites also significantly exceeded the lethal range (>77° F) for trout. At times the water was recorded to be above the lethal threshold for 12 straight hours.

The upper two (Ugstad Rd Upper and Voltze Rd) and lower two (DS Freeway and 12LS005) sites had relatively cold temperatures and could conceivably support coldwater species like brook trout. Two large (9-10") trout were observed at the DS Freeway site during a stream reconnaissance performed by the authors – anecdotal evidence that the water in that reach is hospitable. The spatial distribution of the three sites with warm temperatures extends through the middle of the Kingsbury Creek watershed. This part of the watershed contains several possible sources of temperature loading, including runoff from impervious surfaces in the City of Proctor and the Canadian National rail yard, and substantial portions of removed and/or inadequate riparian vegetation. The stream types in this area are mostly B and C channels – which have higher width/depth ratios and are more prone to warming from direct solar radiation. In contrast, the riparian corridor in the upper reaches – despite some channelization of the stream itself – is relatively undisturbed. Those reaches are mostly deep, narrow E channels with wide, well vegetated riparian corridors. The lower reaches are mostly narrow A channels with plentiful shade provided by healthy old growth cedar and pine forests in the riparian corridor.

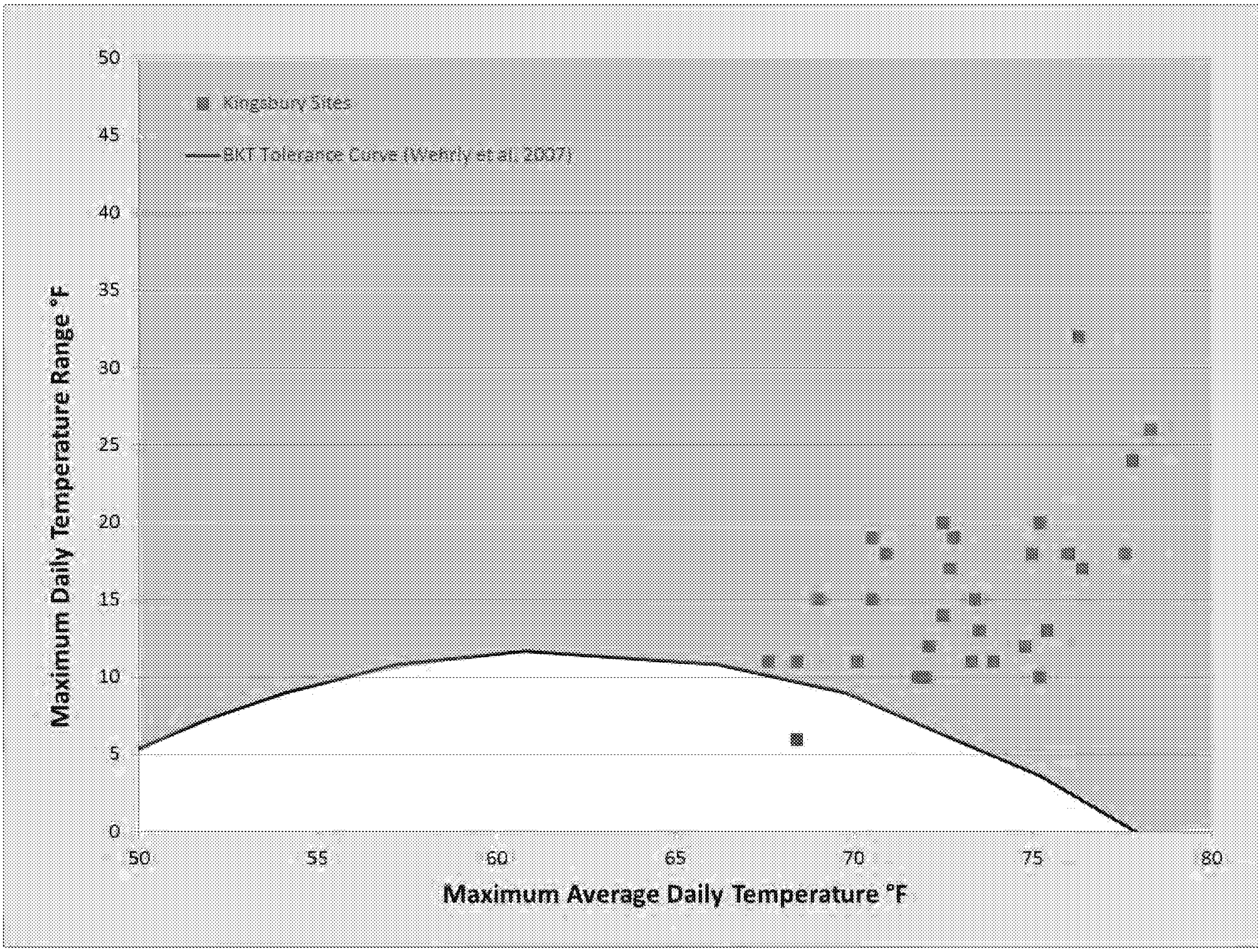


Figure X: Maximum daily temperature range and maximum average daily temperature for all Kingsbury temperature loggers

Recognizing the importance for coldwater species of temperature *fluctuation* as well as high temperature, temperature data for all Kingsbury Creek sites was plotted (Figure X) using similar methodology to a trout temperature tolerance study in Wisconsin and Michigan (Wehrly ,et al.(2007) Field-Based Estimates of Thermal Tolerance Limits for Trout: Incorporating Exposure Time and Temperature Fluctuation, Transactions of the American Fisheries Society, 136:2, 365-374, DOI: 10.1577/T06-163.1). The X-axis represents the highest average daily temperature recorded at each site for the three-month period between June 1 and August 31. The Y-axis represents the highest temperature range recorded in a single day in the same June-August time span. In the aforementioned study, fish and temperature data from streams across Michigan and Wisconsin were plotted. A BKT tolerance curve was developed by running a 95% quantile regression on the sites where BKT were found. That same curve is used in the figure above.

Almost every site falls outside the tolerance limit for BKT, with the exception of 12LS005, which is only August data. This analysis suggests that temperature fluctuation is also a limiting factor for brook trout in Kingsbury Creek in terms of water temperature. Possible causes of high temperature fluctuation are 1) relatively small groundwater contributions in low flow conditions, 2) inadequate stream shading leading to direct solar heating, or 3) heated runoff from impervious urban and industrial portions of the watershed.

Visit Number	Waterbody Name	Field Number	Fish Class	Fish IBI	Coldwater Taxa Present	Coldwater Intolerant %	Coldwater Sensitive Taxa %

	19980006	Kingsbury Creek	98LS003	11	20	0	0.00	25.00
	20121114	Kingsbury Creek	98LS003	11	45	1	22.64	28.57
					Average	0.5	11.32	26.79
Unimpaired Sites	20091057	Dutch Slough	09LS014	11	49	1	9.09	40.00
	20091147	Hay Creek	97LS108	11	71	2	51.49	42.86
	20091156	Keene Creek	95LS028	11	61	1	27.47	25.00
	20091146	Little Otter Creek	09LS116	11	51	2	2.33	30.00
	20091012	Midway River	09LS117	11	55	2	15.43	30.77
	20091013	Midway River	09LS118	11	61	3	15.71	35.71
	20091068	Midway River	09LS117	11	59	2	23.44	30.77
	20091037	Pine River	09LS013	11	50	2	5.42	22.73
	20091065	Pine River	09LS013	11	53	2	1.78	31.25
	19970052	Trib. to Midway River	97LS039	11	63	2	2.74	57.14
	20091153	Trib. to Midway River	97LS112	11	52	1	23.38	44.44
	19970087	White Pine River	97LS083	11	63	2	15.55	38.46
	20091148	White Pine River	09LS115	11	55	1	5.88	28.57
					Average	1.8	15.36	35.21

Table X: Coldwater metrics of Kingsbury Creek and unimpaired coldwater streams in the St. Louis River watershed

An analysis of coldwater biological metrics reaffirms temperature as a stressor compared with unimpaired coldwater sites in the St. Louis River watershed. From two reportable visits to Kingsbury biosite 98LS003, the average coldwater taxa present was 0.5, the average percent of coldwater intolerant individuals was 11.32%, and the average coldwater sensitive taxa percent was 26.79% (Table X). In contrast, the numbers for the unimpaired coldwater biosites are 1.8, 15.36% and 35.21%, respectively. The metrics for the 2012 visit to 98LS003 may also be artificially high due to the presence of DNR-stocked brook trout in Kingsbury Creek (source). Regardless, the fish population in Kingsbury Creek does not represent a healthy coldwater community.

Restoration/Protection Strategies to Reduce Water Temperatures

1. Improve riparian corridor
    a. Increase width of corridor by reducing the size of or moving the rail yard, golf course, and baseball fields.
    b. Plant long-living native canopy trees near the stream to increase shading
2. Reduce temperature loading from stormwater
    a. Encourage residential stormwater retention with rain barrels, swales and rain gardens
    b. Install curb-cut rain gardens and stormwater retention ponds in heavily developed areas
3. Restore stable dimension, pattern, and profile to reaches of stream that have been altered, straightened, or that have high width/depth ratios

Dissolved Oxygen

The fish community of Kingsbury Creek is generally comprised of fish species that can be considered "neutral" in terms of their tolerance to low dissolved oxygen conditions (figure BLANK). Creek chub and white sucker are examples of fish species that fall within this tolerance class and are abundant in many reaches of Kingsbury Creek.

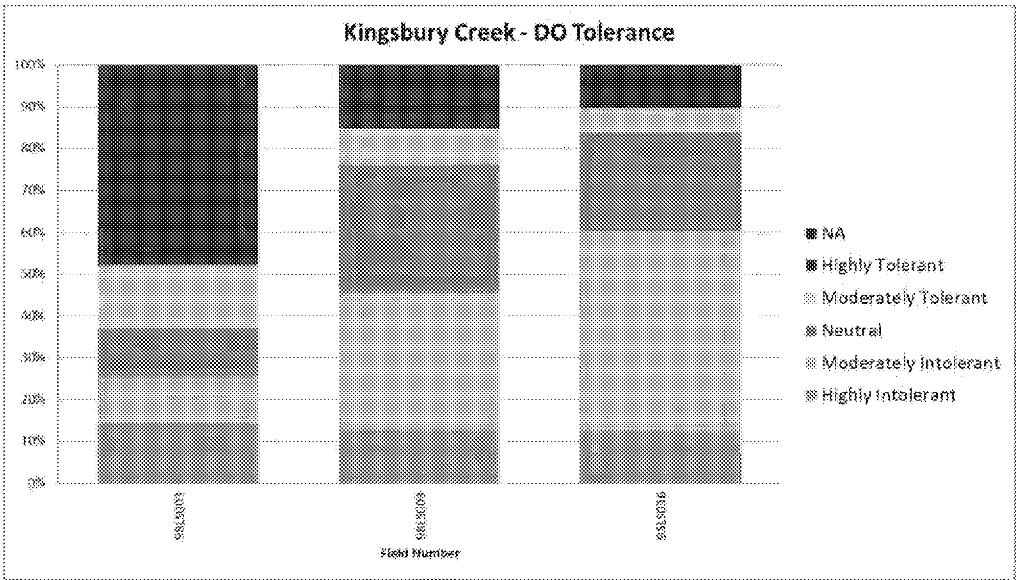
Localized areas of the creek show a higher proportion of fish species that can be considered highly tolerant of lower dissolved oxygen concentrations. This is particularly apparent in the corridor along the Proctor (MN) athletic complex, which lies just downstream of the city of Proctor (stations 98LS003 and 95LS036). Fish species associated with low dissolved oxygen conditions and poor overall habitat conditions, such as fathead minnow and central mudminnow, were observed in fairly large numbers within this reach. Several minnow species common to wetland and headwater stream environments were also present (northern redbelly dace, pearl dace, finescale dace). The proportion of these low DO tolerant species to more sensitive fish taxa at this monitoring station varies considerably between the two sampling events (note results for station 98LS003 in figure BLANK), which may indicate that suitable DO conditions may exist when ambient conditions are favorable.

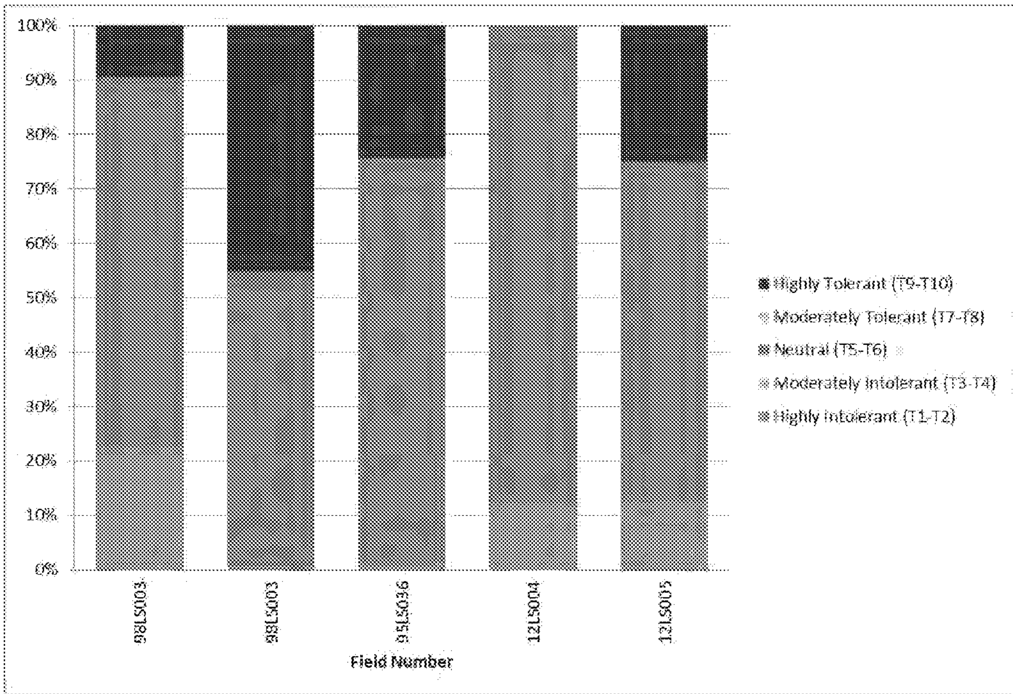
Brook trout and brown trout were the only fish taxa observed that can be considered "highly intolerant" to low dissolved oxygen conditions. Minnesota DNR routinely stocks catchable size trout in several reaches of Kingsbury Creek, and it is likely that all of the trout observed were introduced to the stream through stocking. The twenty-four brook trout individuals collected during the 2012 sampling of station 98LS003 are believed to be stocked fish, as there were no appreciable differences in size between the fish sampled and eroded caudal fins were observed in a large number of the fish. Eroded fins are a common deformity in stocked fish due to time spent in holding tanks.

A single brook trout was observed at both station 12LS004 and 95LS036. Although there may be some natural reproduction occurring in some areas of Kingsbury Creek, historical and current data from this stream suggest that these fish are also the result of stocking efforts.

The fish assemblage of Kingsbury Creek does not provide overwhelming evidence for or against low dissolved oxygen as a stressor. However, after discounting stocked brook and brown trout, low-DO tolerant fish taxa are more abundant in Kingsbury Creek than taxa which are moderately or highly intolerant of low dissolved oxygen. The lack of self-sustaining populations of DO-sensitive fish species like brook trout and longnose dace provide some evidence in support of low DO as a stressor.

Based on the most recent data collected in 2009 and 2011, Kingsbury Creek stations 98LS003 and 95LS036 show a relatively high proportion of macroinverterbates that are moderately or highly sensitive to low dissolved oxygen conditions (figure BLANK). Between 40 and 60% of the organisms observed at these sites in 2009 and 2011 can be considered sensitive to low dissolved oxygen. In contrast, the 1998 results from station 98LS003 show a high percentage of low-DO tolerant taxa in the sample (over 60%). The '98 sample contained relatively large populations of several low-DO tolerant taxa that were not present in the most recent sample, such as the isopod *Asellus* (aquatic sowbug), the non-biting midge *Dicrotendipes*, and the air-breathing snail *Helisoma*.


Kingsbury Creek - DO Tolerance
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
98LS003
98LS003
95LS036
Field Number
NA
Highly Tolerant
Moderately Tolerant
Neutral
Moderately Intolerant
Highly Intolerant


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
98LS003
98LS003
95LS036
12LS004
12LS005
Field Number
Highly Tolerant (T9-T10)
Moderately Tolerant (T7-T8)
Neutral (T5-T6)
Moderately Intolerant (T3-T4)
Highly Intolerant (T1-T2)

Dissolved Oxygen

TSS/Turbidity

Ionic Strength

Metals (Aluminum, Copper, Lead)

Habitat

A. Miller Creek

a. Temperature (reference existing Study)
b. Dissolved Oxygen
c. TSS/Turbidity
d. Ionic Strength (Chloride)

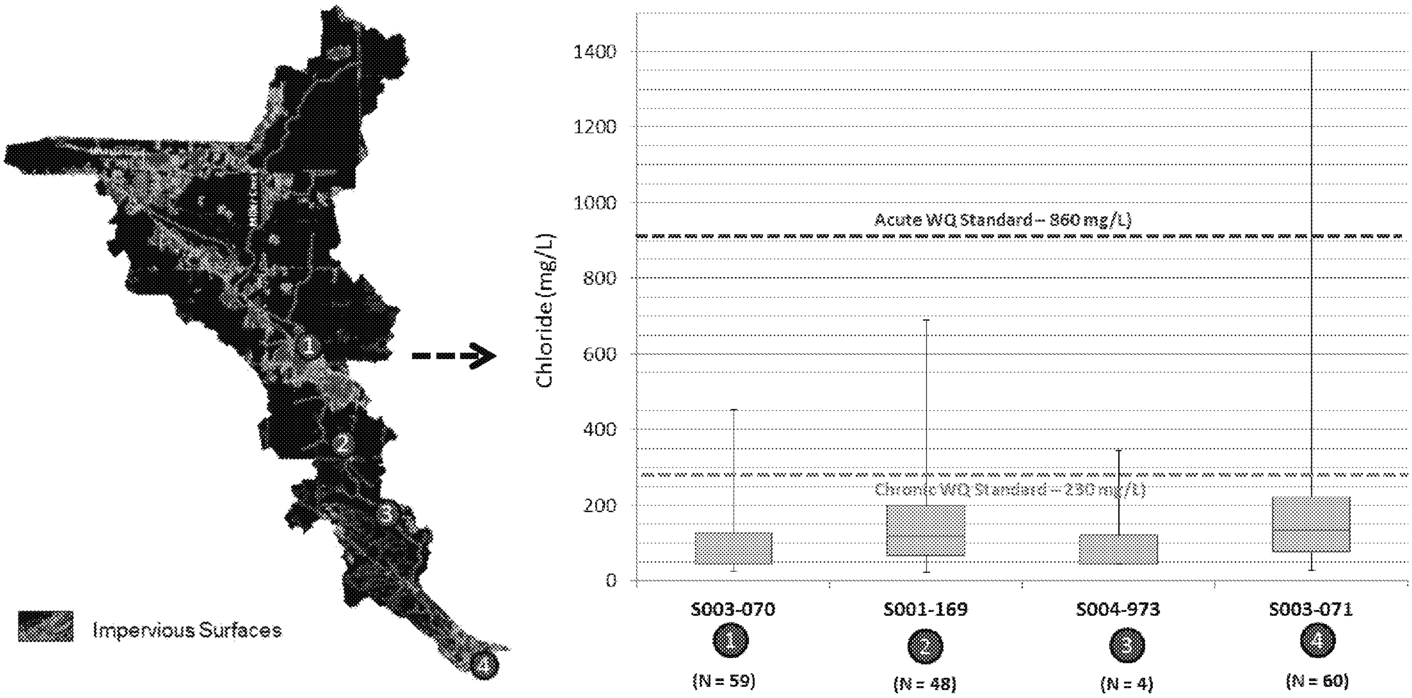
Elevated Ionic Strength / Chloride Toxicity

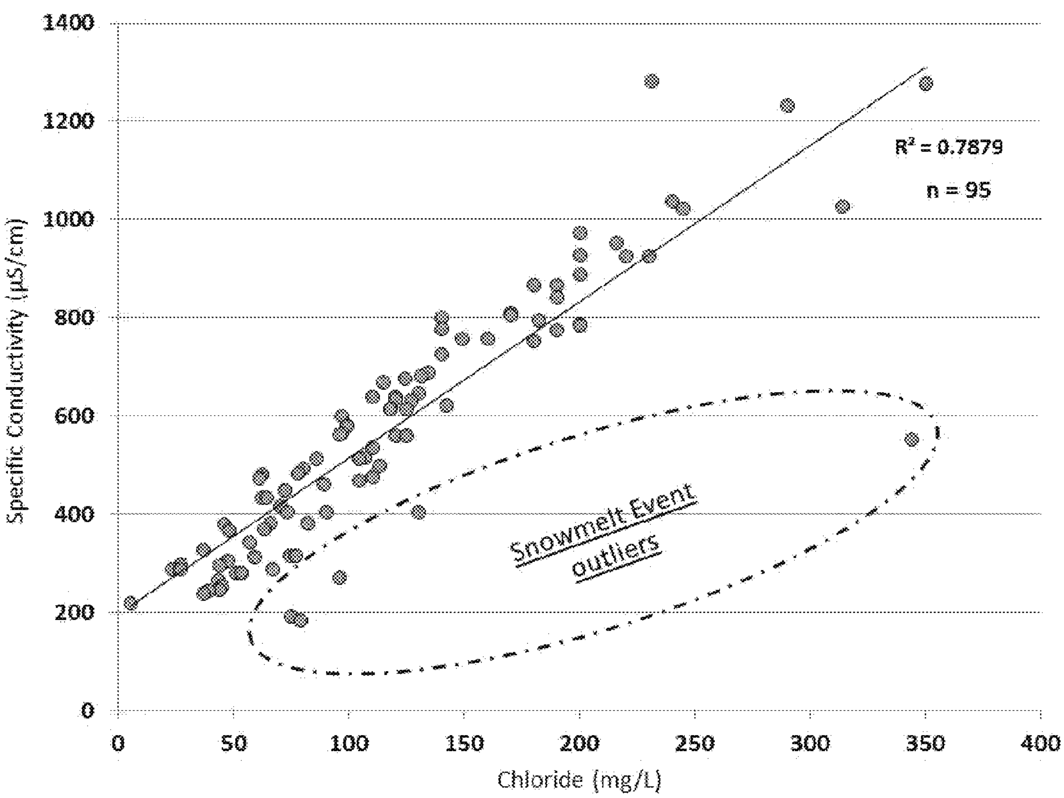
Elevated chloride concentrations and high specific conductivity are candidate stressors that have received a significant amount of attention in the Miller Creek watershed due to the level of urban and commercial development. A study completed by Duluth MPCA (Anderson et al., 2000) documented some of the effects of urbanization and road salt application on several Duluth area streams, including Miller Creek. This study, along with more contemporary data that is available for these parameters, will be evaluated in this section as potential causes for macroinvertebrate IBI (MIBI) impairment.

Chloride

The recommended national criteria and current Minnesota water quality standard for chloride are established at a chronic value of 230 mg chloride/liter, implemented as a four-day average concentration and acute (maximum concentration) of 860 mg chloride / liter, implemented as a one-day average concentration.

Miller Creek was listed as impaired during the 2010 assessment cycle for failing to meet the state water quality standard for chloride (230 mg/L).


Impervious Surfaces
1
2
3
4
1400
1200
1000
800
600
400
200
0
Chloride (mg/L)
Acute WQ Standard – 860 mg/L)
Chronic WQ Standard – 230 mg/L)
S003-070
(N = 59)
S001-169
(N = 48)
S004-973
(N = 4)
S003-071
(N = 60)


1400
1200
1000
800
600
400
200
0
Specific Conductivity (µS/cm)
$R^2 = 0.7879$
n = 95
Snowmelt Event outliers
0
50
100
150
200
250
300
350
400
Chloride (mg/L)

e. Habitat

Mille Lacs – Northshore Highlands Watershed Zone

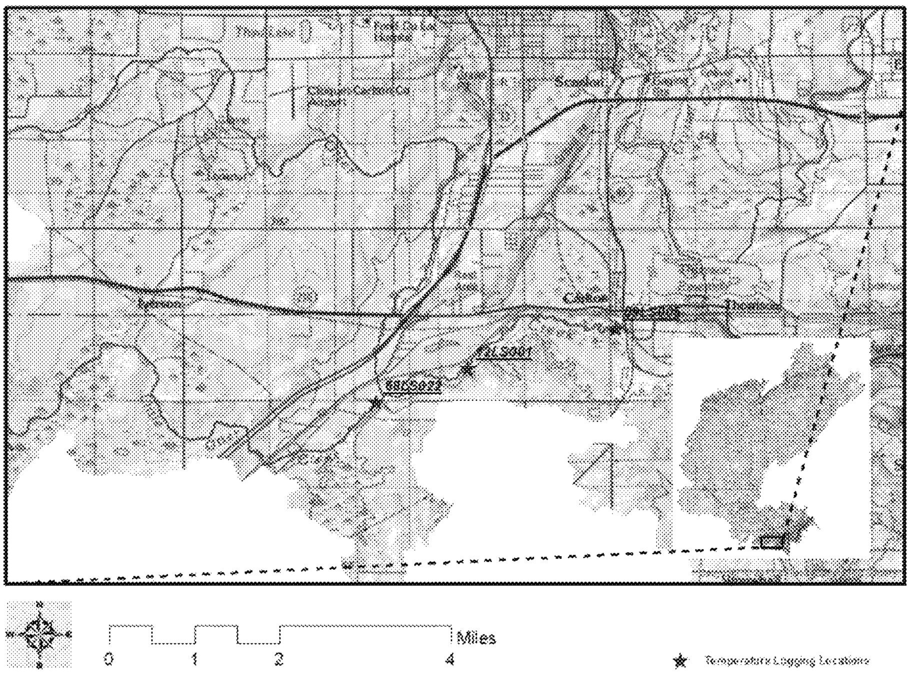
Otter Creek is the lone impaired stream in this watershed zone, and it appears to share similar symptoms of impairment to coldwater streams in the DUC watershed zone. Otter Creek originates in a series of wetlands, and meanders through a riparian corridor dominated by alder and willow shrubs, interspersed with localized stands of pine and several bedrock outcroppings. Over the past few decades, land in this watershed has been increasingly developed due to the expansion of a large casino, new housing developments, and several gravel mining pits within close proximity of the stream.

Like many of the other impaired streams in the SLRW, Otter Creek supports few sensitive macroinvertebrate species, and species tolerant of pollution and other forms of disturbance are relatively common. Data from this stream also indicates large proportion of macroinvertebrate taxa from the functional feeding group (FFG) "collector-gatherers." These organisms feed by collecting fine particulate organic matter (segments of leaves, twigs, and other plant matter). To be continued.....

Analysis of Candidate Stressors for Impaired Streams

Otter Creek

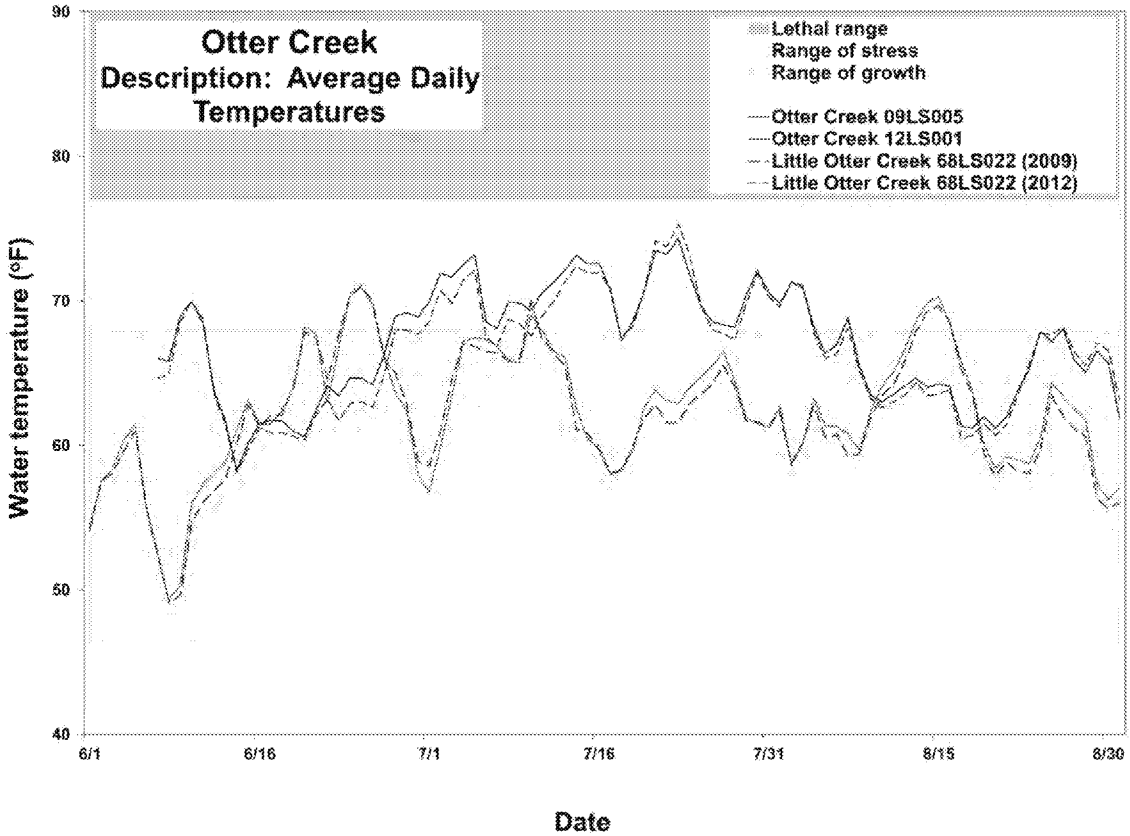
Temperature data was collected at three MPCA biosites on Otter Creek: 09LS005 south of the town of Carlton, 12LS001 near the Munger Trail, and 68LS022 upstream of the mouth of Little Otter Creek. Only data between June 1 and August 31 were analyzed – when stream temperatures are most likely to exceed the stress threshold for coldwater-sensitive macroinvertebrate species.



8. Figure X: HOBO logger locations on Otter Creek

Figure X shows Otter Creek's susceptibility to ambient atmoshperic conditions. The logger installed in 2009 (solid red line) recorded average daily temperatures that exceeded the stress threshold for only three brief periods. As has been stated before, the 2009 summer was much colder than normal. Conversely, the summer of 2012 (solid black line) saw average daily temperatures in Otter Creek that exceeded the stress threshold of 68° F for essentially the entire month of July. The summer of 2012 was warmer than average, but closer to normal than the summer of 2009.

The average daily temperature in Little Otter Creek strongly mirrors that of Otter Creek. In fact, during both recorded periods the average water temperature in Little Otter Creek rarely strays by even a degree Fahrenheit from the average in Otter Creek (even in 2009, when the temperature loggers were more than three miles apart). That observation, combined with the fact that the Macroinvertebrate IBI score in Little Otter Creek was above the threshold and within the upper confidence limit, suggests that water temperature should not be considered a stressor and something else is limiting the macroinvertebrate population in Otter Creek.



Habitat

Meadowlands Floodwood Peat Bog

Watershed Zone Overview

The Meadowlands Floodwood Peat Bog (MF-PB) watershed zone exhibits one of the highest impairment rates in the SLRW. The impaired streams within this watershed (listed in table BLANK) show many similarities in terms of the character of the streams, symptoms of impairment, and potential stressors. For the most part, streams of this watershed zone are very low gradient, and are lacking coarse substrates and riffle-run habitats. With the exception of the impaired reach on the mainstem of the St. Louis River, all of the impairments are found on small tributary streams draining a network of ditches within the expansive Meadowlands Sax-Zim peat bog. All of these streams are severely tea-stained in color and low in alkalinity, which is a natural background condition that may be limiting the diversity and abundance of aquatic life.

Figure BLANK:

The impaired streams of this watershed zone generally support few species of fish, and overall fish abundance is also low in comparison with other streams of similar size in the SLRW. Populations of non-tolerant headwater minnow species, such as northern redbelly dace, pearl dace, and finescale dace were lacking at the impaired sites in this watershed zone. Instead, the impaired streams were typically dominated by species highly tolerant to low dissolved oxygen conditions (central mudminnow, black bullhead) or species that are known to migrate into low gradient streams seasonally (northern pike).

A lack of insectivorous fish species is another symptom of impairment that was common across most of the impaired stations in the MF-PB watershed zone. This may be an indication that the food base in degraded streams has been altered by habitat degradation, eutrophication, or other processes. The insect life available as prey may also be lower in these streams due to the natural background conditions found in this watershed zone (low alkalinity, lack of coarse substrates/riffle habitats). Taxa richness of simple lithophils (fish that require non-embedded gravels or cobble for spawning) was also very low at most of the impaired locations, which is another symptom that can be linked to a lack of coarse substrate in these streams.

The macroinvertebrate communities at impaired sites within this watershed zone tend to be "unbalanced," or in other words, dominated by several taxa. For Example, the five most common taxa in Vaara Creek and Skunk Creek accounted for 85% and 73% of the total individuals sampled. An unbalanced macroinvertebrate community can be an indicator of reduced habitat complexity or the presence of a stressor that would effect a broad range of taxa.

Many of the impaired sites in this IBI class scored poorly in a metric that measuring the richness of "clinger" macroinvertebrate taxa. These taxa maintain a relatively fixed position on firm substrates, often in areas where current velocities are higher. Their reliance on coarse substrate and interstitial spaces between substrate particles as habitat renders them vulnerable to benthic habitat degradation, particularly in the form of sedimentation (embeddedness).

Analysis of Candidate Stressors for Impaired Streams

St. Louis River

{Intro/MAP of Impaired Reach}

Habitat

The impaired reach of the St. Louis River extends from the confluence with the Whiteface River down to the confluence with the Floodwood River. This reach flows through the nearly level bed of Glacial Lake Upham, and as a result it has a much lower gradient than other reaches of the river, and a streambed dominated by fine particles (silt and clay). These conditions, coupled with the infertile geological features in this region, have been cited as potential causes for limited fisheries productivity in this reach of the river (Lindgren et al., 2006). Macroinvertebrate IBI scores were below the impairment threshold within this same reach, but elsewhere on the river, scores were generally good to excellent.

Several M-IBI metrics appear to be responding negatively to localized stressors within this low-gradient, habitat-limited reach of the St. Louis River. Similar to observations of the fish community in this reach of the river, overall macroinvertebrate taxa richness begins to decline as the river enters the area of former Glacial Lake Upham. Taxa richness counts remain suppressed at several monitoring stations extending nearly 20 miles downstream of the impaired reach (figure BLANK). These stations are also lower in gradient, and may be impacted by glacial lake sediments and several tributary streams that are heavily influenced by bogs and wetlands.

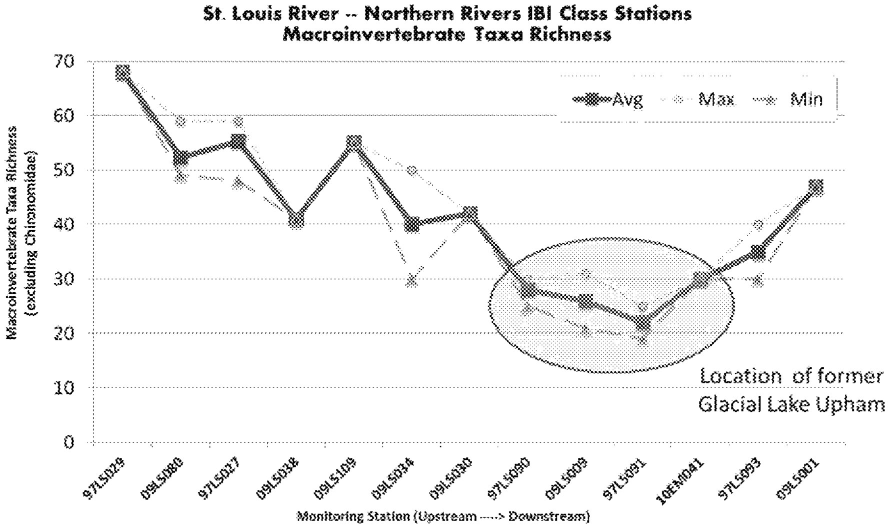


Figure BLANK:

In addition to low overall taxa richness, macroinvertebrate communities within the impaired reach tended to be dominated by several taxa. Observations from station 97LS090, which is the only station located on the impaired segment, show a community that was dominated by Leptophlebiidae (Prong-gilled mayflies) and Hyallela (freshwater amphipods). These two genera accounted for 88% and 84% of the macroinvertebrates counted from samples collected during two visits to 97LS090 in the fall of 2009. Leptophlebiidae taxa were not observed during a sampling visit to this station in 2011, and overall, there was considerably more balance among the taxa that were present.

Skunk Creek

Dissolved Oxygen

pH / Low Ionic Strength

Habitat

Vaara Creek

Dissolved Oxygen

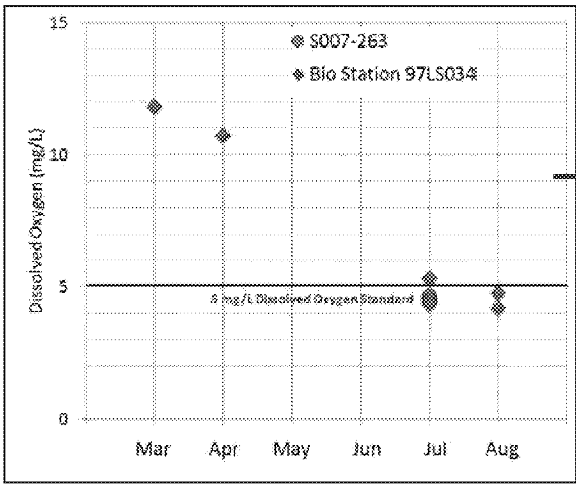
Available Dissolved Oxygen Data

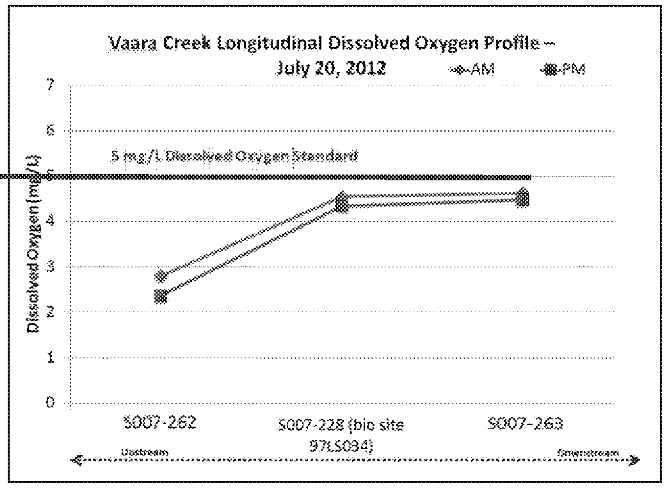
Limited instantaneous dissolved oxygen (DO) measurements are available from two stations on Vaara Creek. Station 97LS034 (biological monitoring station) was sampled a total of seven times, with the majority of the DO readings collected in July and August. Summer baseflow DO concentrations at this station hovered near the warmwater DO standard of 5 mg/L, with most of the readings falling just under 5 mg/L. The other monitoring station with dissolved oxygen data, S007-263, is located approximately 0.4 miles downstream of the biological monitoring station near the confluence with the Floodwood River. The area around S007-263 appears to flood frequently and may be influenced by backwater from the Floodwood River. Dissolved oxygen data at this site are limited, but this reach appears to have DO concentrations similar to those observed at the biological monitoring station.

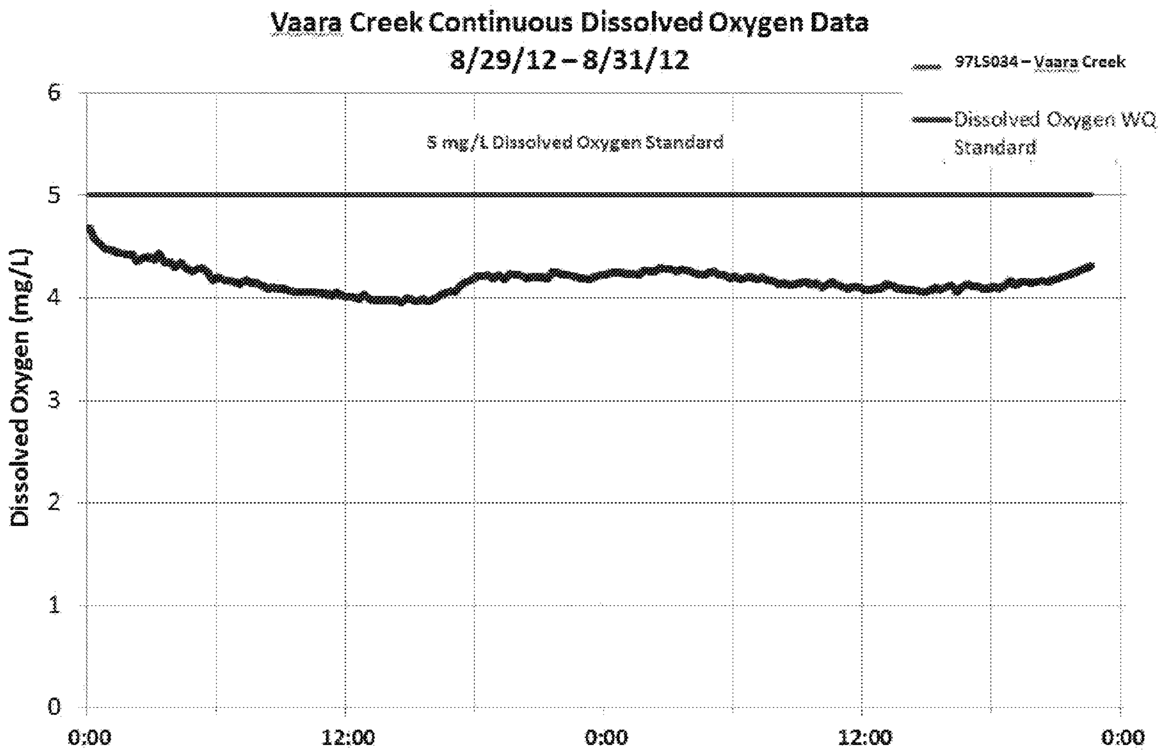
A longitudinal DO profile was conducted at three monitoring stations on Vaara Creek in July of 2012. The sample size was limited to three stations due to the lack of road crossings in the watershed. Still, a pattern of lower DO concentrations (below 3 mg/L) in the headwaters increasing to around 4.5 mg/L downstream was evident. The difference between morning and afternoon measurements was negligible, which is another indicator that diurnal DO flux is extremely low in this stream.

A single continuous DO monitoring period on Vaara Creek was initiated in late August of 2012. The 46.75 hour monitoring period was shorter than the typical DO profiles collected throughout the SLRW as part of the Stressor Identification study. Dissolved oxygen concentrations ranged from a minimum of 3.96 mg/L to a maximum of 4.68 mg/L, remaining below the 5 mg/L warmwater standard for the entire monitoring period (figure BLANK). Dissolved oxygen flux was extremely low (0.33 mg/L), which is similar to other impaired streams in the region with wetland dominated land-cover and heavily bog-stained water. Morning and evening DO measurements were also taken on 7/20/2012 (9:12 am and 3:00 pm) to observe DO flux over that time period. A DO flux of 0.20 mg/L was observed between those two sampling points, and DO concentrations were in the range of 4.35 – 4.55 mg/L.

The available dissolved oxygen data shows that Vaara Creek routinely fails to meet the warmwater DO standard of 5 mg/L. Although data are somewhat limited for this stream, the DO concentrations observed are consistently below 5 mg/L during summer low flow periods







Monitoring Period	# of Readings	Min (mg/L)	Max (mg/L)	24-Hour Flux Data		Warm Water Threshol - 5 mg/L		
				Average (mg/L)	Max (mg/L)	% Readings below	Avg. Duration below (hrs)	Max Duration below (hrs)
8/29/2012 - 8/31/2012	187	3.96	4.68	0.33	0.33	100.00%	46.75	46.75

<u>Sources and Pathways Contributing to Low Dissolved Oxygen</u>

<u>Wetlands</u>

Nearly 80% of the Vaara Creek watershed is classified as wetland. The mainstem of Vaara Creek, and its tributary streams emerge from an expansive region of wetlands that are underlain by mostly peat, all hydric soils (figure BLANK). Hydric soils, by definition, are permanently or seasonally saturated by water, resulting in anaerobic conditions. These wetland areas are likely delivering water with depleted oxygen levels to Vaara Creek throughout its length.

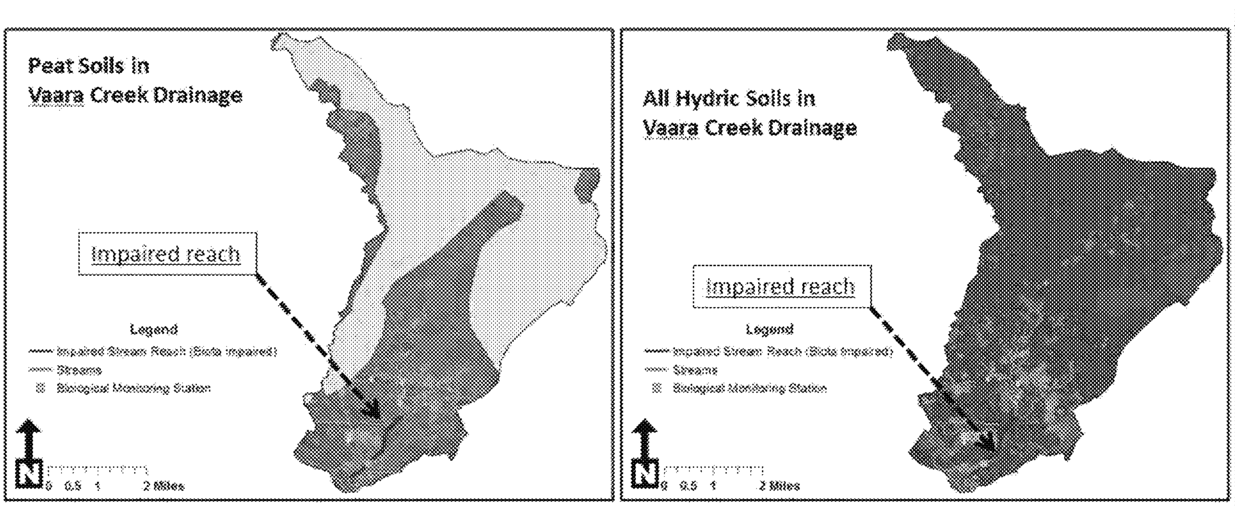


Figure BLANK:

Nutrients and Productivity

Total phosphorous (TP) data are limited for Vaara Creek, but available data suggests that TP concentrations are slightly elevated, and may regularly exceed river nutrient criteria targets for Northern Minnesota. The three results, all from low flow mid-summer conditions, range from 0.032 mg/L to 0.090 mg/L. There are several agricultural fields and small feedlots in the Vaara Creek watershed that may be contributing to phosphorous loading in the watershed, but natural sources of phosphorous (esp. wetlands) are likely a significant source as well.

The river nutrient criteria in development for streams and rivers of Minnesota uses TP as the primary nutrient variable, as well as a series of response variables (dissolved oxygen flux, biological oxygen demand, chlorophyll-a) that relate specifically to the stressor caused by elevated nutrient concentrations. The only paired data set for TP and response variables are from samples that were taken during the 48-hr continuous monitoring period in August of 2012 (figure BLANK). TP concentration was below the nutrient criteria of 0.055 mg/L, and DO flux (0.33 mg/L) was well below 4.0 mg/L. Biological oxygen demand narrowly exceeded the nutrient criteria guideline, but the higher BOD values are likely due to the breaking down of organic compounds produced in the peat bogs upstream, and not primary production in the water column. Chlorophyl-a data was not collected during the continuous monitoring period or at any other time in the SID study. However, chl-a values are expected to well within river nutrient criteria due to the tannin stained water of Vaara Creek limiting algae growth. Low dissolved oxygen concentrations in Vaara Creek do not appear to be driven by nutrient enrichment and river eutrophication.

Table BLANK:

	Total Phosphorous (TP) (mg/L)	24-hr DO Flux (mg/L)	Biological Oxygen Demand (mg/L)	Chlorophyl-a (µg/L)
Vaara Creek @ 97LS034 (08/29/2012)	0.032	0.33	1.7	No Data
Draft River Nutrient Criteria (Northern MN)	0.055	≤ 4.0	≤ 1.5	< 10

Biological Response to Low Dissolved Oxygen

Fish sampling was conducted at Vaara Creeks station 97LS034 in 1997 and 2009. Data from both sampling events shows a fish community dominated by fish taxa that are tolerant of low dissolved oxygen conditions. In 1997, 89% of the total fish sampled were species that can be considered tolerant to low dissolved oxygen, and in 2009, this percentage increased to 100%. Overall fish abundance was very low in the 2009 sample, with only 12 individuals caught. This was a significantly lower catch than the 1997 survey in which 97 individuals were sampled. Of the 97 fish sampled in 1997, 73 (75%) were central mudminnow, a species that is easily one of the most low-DO tolerant species found in Minnesota.

The macroinvertebrate assemblage in Vaara Creek consists largely of taxa that are tolerant of low dissolved oxygen concentrations. Taking into consideration both monitoring visits, approximately 80-90% of the macroinvertebrates sampled at Vaara Creek station 97LS034 were moderately tolerant or highly tolerant of low dissolved oxygen levels. Mayflies from the genus *Paraleptophlebia* were the most abundant taxa represented in the 1997 sample by a large margin. These mayflies are part of the family Leptophlebiidae (prong-gilled mayflies), and can be considered moderately tolerant of low dissolved oxygen conditions. *Paraleptophlebia* were absent from the sample collected in 2009, and instead, the amphipod *Hyalella* was dominant. *Hyalella* are tolerant of many stressors, including low DO, are abundant in many other impaired streams in the SLRW with low dissolved oxygen concentrations.

The fish and macroinvertebrate DO index values for Vaara Creek offer further evidence in support of low dissolved oxygen concentrations as a stressor in this watershed. DO index scores in Vaara Creek are lower than the vast majority of scores recorded from reference streams of the same IBI class (figure BLANK). A lower DO index score indicates a community that is more tolerant of low dissolved oxygen conditions. Other biological data that could support low dissolved oxygen as a stressor in this stream include low overall fish abundance, a high percentage of "legless" macroinvertebrate taxa (aquatic worms, fly larvae, midges), and low EPT taxa percent.

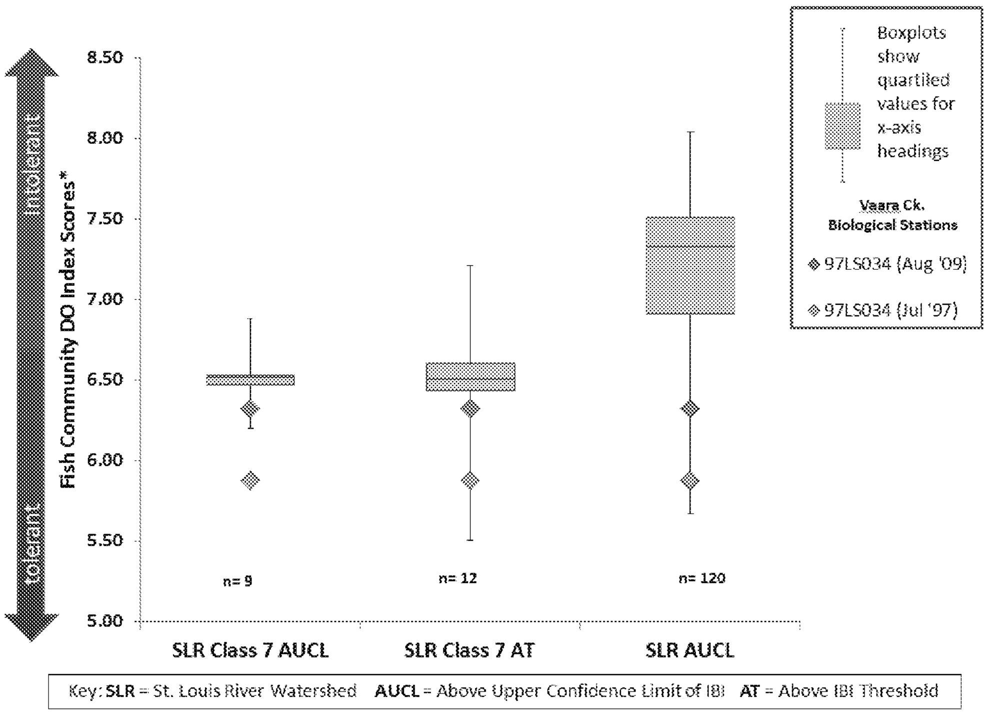


Figure BLANK:

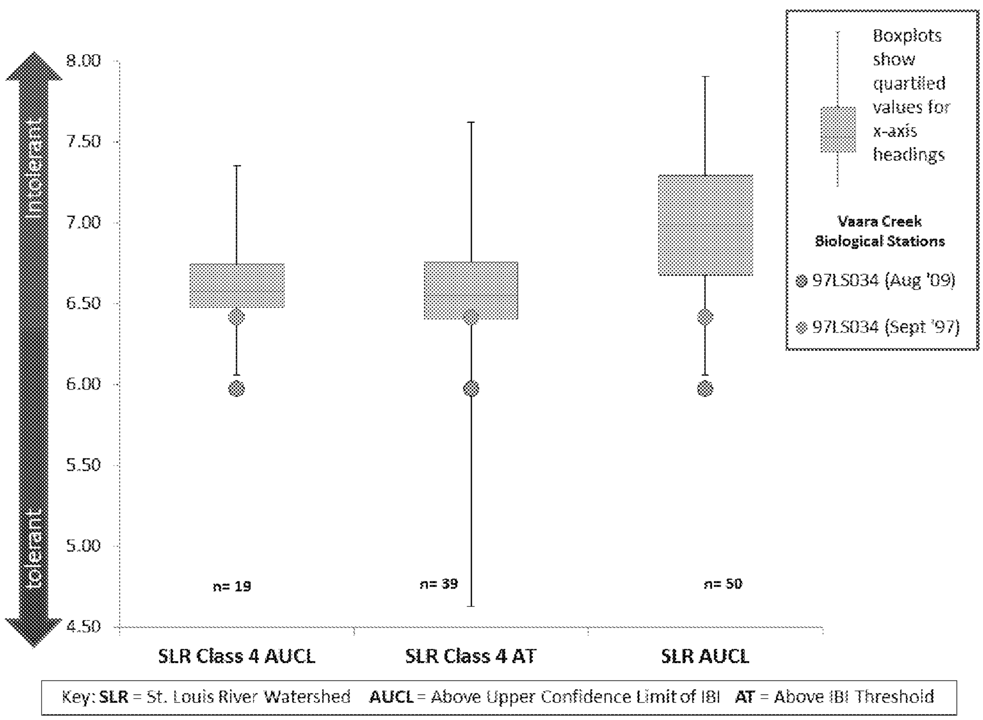


Figure BLANK:

pH / Low Ionic Strength

Habitat

Sand Creek

TSS / Turbidity

TSS data for Sand Creek are somewhat limited, with one exeedence of the WQ threshold in four sampling events. A TSS concentration of 24 mg/L observed during a snowmelt sampling event on 04/18/2012 accounts for the only exceedence of the 15 mg/L TSS WQS. Other TSS results from mid-summer months range from 3.2 mg/L to 15 mg/L. The 15 mg/L result came two weeks after a major flood event in the watershed, and is probably not representative of typical summer low flow conditions. Transparency results indicate that water clarity is adequate for supporting aquatic life, as 10 out of 10 measurements met the applicable transparency WQS.

Sources and Pathways of TSS

Indicators of stream channel instability were noted in Sand Creek during several reconnaissance outings, particularly in the impaired reach. Moderate to severe bank erosion, middle channel bars, and high width-to-depth ratios are common in the lower portions of Sand Creek.

Fish Response to TSS

A total of two biological monitoring stations are located on Sand Creek, one on the impaired reach (09LS033), and one upstream of the impaired reach (98LS047). Comparisons between these stations are somewhat difficult to make due to discrepancies in sampling year – staion 98LS047 was sampled once in 1998, while station 09LS033 was sampled a single time in 2009. Fish community data from these two stations show a different level of tolerance to TSS. Over 65% of the fish community at station 98LS047

a. Habitat
b. pH / Low Ionic Strength

Stony Creek

Intro to watershed / map/ land-use / Impairments

Biology Overview

Stream	Station	Drainage Area	% Slope	Sinuosity	Fish Class	FishIBI	Fish IBI Standard
Stony Creek	67LS020	19.00	0.03	2.17	7	32	40
Stony Creek	09LS036	21.54	0.06	2.30	6	39 / 39	40

Symptoms of Biological Impairment (Fish)	Symptoms of Biological Impairment (Macroinvertebrates)
• Low fish counts	• Low taxa richness

• Lack of insectivorous minnow sp. • Lack of headwaters minnow sp. • Lack of sensitive fish taxa	• Low Relative Abundance of Collector-Filterer Taxa • Lack of intolerant taxa • Low relative abundance of trichopteran (caddisfly) taxa

Candidate Causes for Impairment

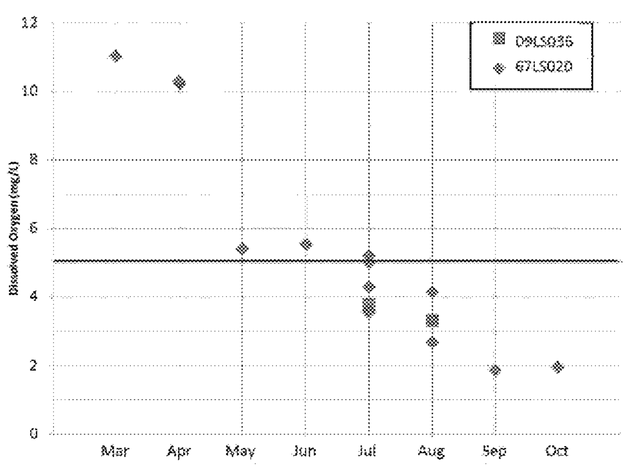
Symptoms of Biological Impairment (Fish)
•

Evaluation of Candidate Causes for Impairment

Dissolved Oxygen

Instantaneous dissolved oxygen (DO) data are available for two stations on Stony Creek, both of which have co-located biological monitoring data. Based on the available data, DO concentrations in Stony Creek regularly fall below the 5 mg/L warmwater standard during the months of July through October (figure BLANK). During these periods of lower DO concentrations, stream stage has generally been extremely low and current velocities have been imperceptible. The picture of station 09LS036 in figure BLANK shows an example of the low flow conditions that are commonly observed during the late summer and early fall months on this stream. Although there remains a significant amount of water in the channel, there often is no perceivable flow. At the time this photo was taken (9/12/2012 @ 11:00), the dissolved oxygen concentration was 1.88 mg/L.

Instantaneous measurements were also collected longitudinally along Stony Creek in order to compare DO concentrations from different stream reaches under similar ambient conditions. The results, shown in figure BLANK, show low DO conditions (at or below 3 mg/L) throughout most of Stony Creek, with lower concentrations in the headwaters and tributary streams. Similar to the continuous DO monitoring results, the longitudinal data show very low diurnal change in DO concentrations.



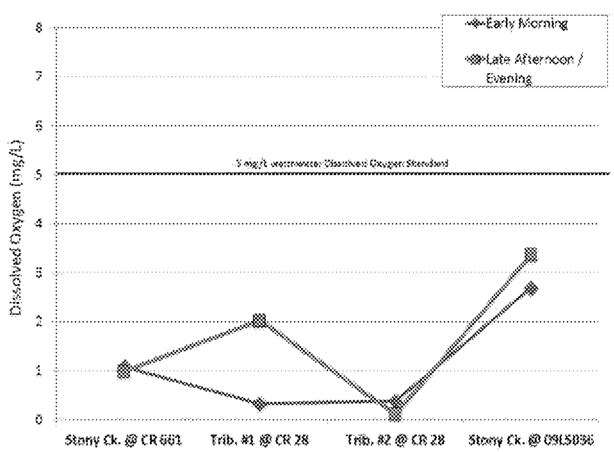
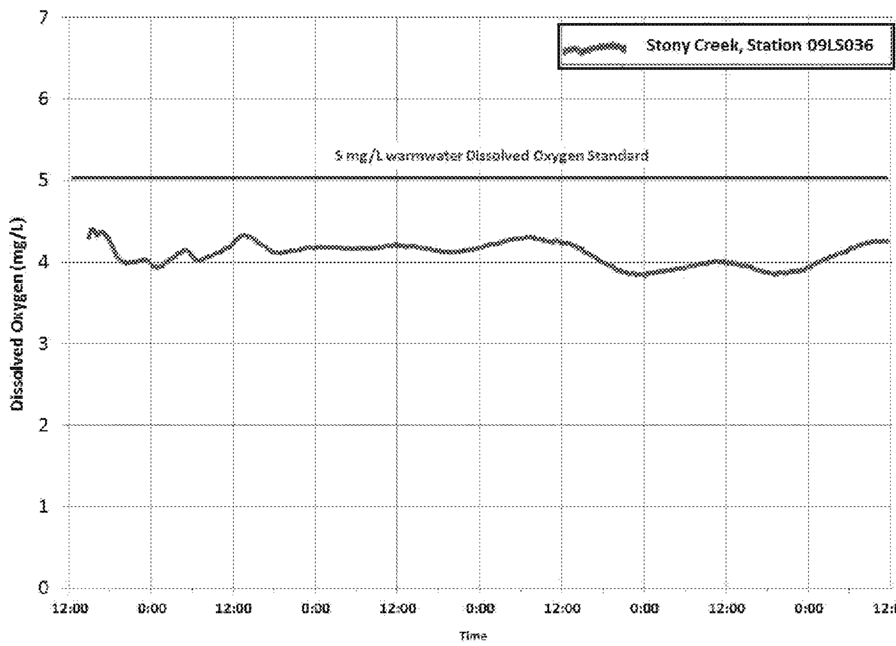


Figure BLANK:

Dissolved oxygen and other field parameters (temperature, pH, Sp. Conductivity) were measured continuously over a five day period from 7/13/2012 to 7/18/2012 at station 09LS036. DO concentrations observed during this monitoring period ranged from 3.83 mg/L to 4.40 mg/L, with 100% of the readings falling below the 5 mg/L warmwater DO threshold (figure BLANK). DO flux was very low (less than 0.50 mg/L), which suggests that primary productivity in Stony Creek is minimal. Although nutrient concentrations in Stony Creek can be relatively high, water clarity is reduced due to heavy tannin stain and does not provide favorable conditions for supporting the growth of aquatic plants or algae.



Dates of Monitoring Period	# of Readings	Min (mg/L)	Max (mg/L)	24-Hour Flux Data Average (mg/L)	Max (mg/L)	% Readings below Warmwater DO Threshold - (5 mg/L)
7/13/2012 – 7/18/2012	486	3.83	4.40	0.29	0.47	100%

Sources and Pathways Contributing to Low Dissolved Oxygen

Total phosphorous (TP) concentrations in Stony Creek are elevated well above river nutrient criteria for northern Minnesota. TP concentrations during mid-summer to early fall baseflow conditions are generally greater than 0.100 mg/L. A maximum TP concentration of 0.240 mg/L was observed in Stony Creek during a snowmelt runoff event in March 2012.

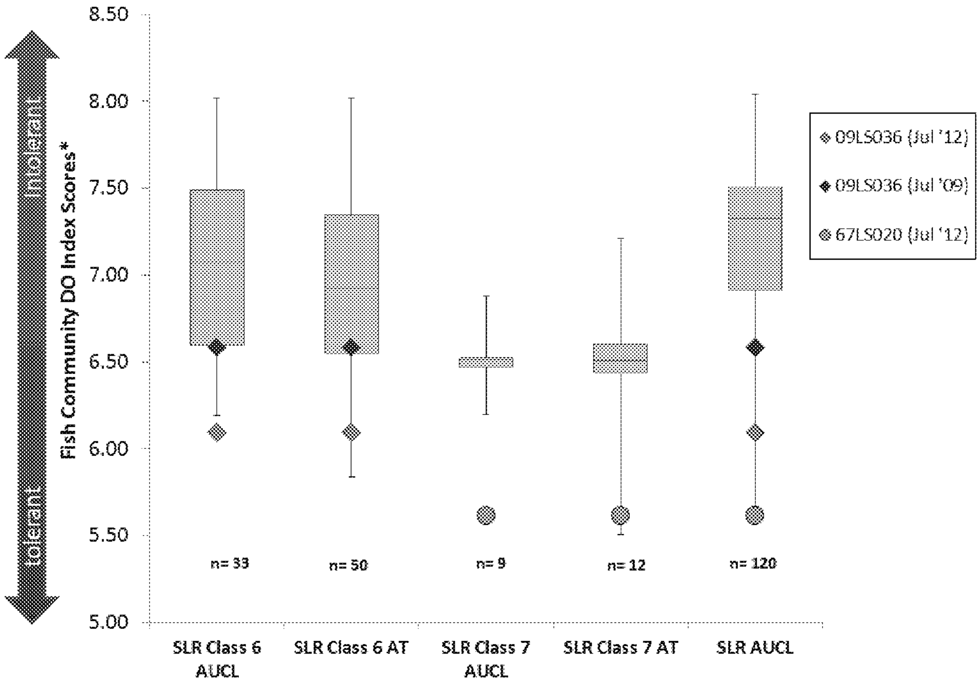
Biological Response to Low Dissolved Oxygen

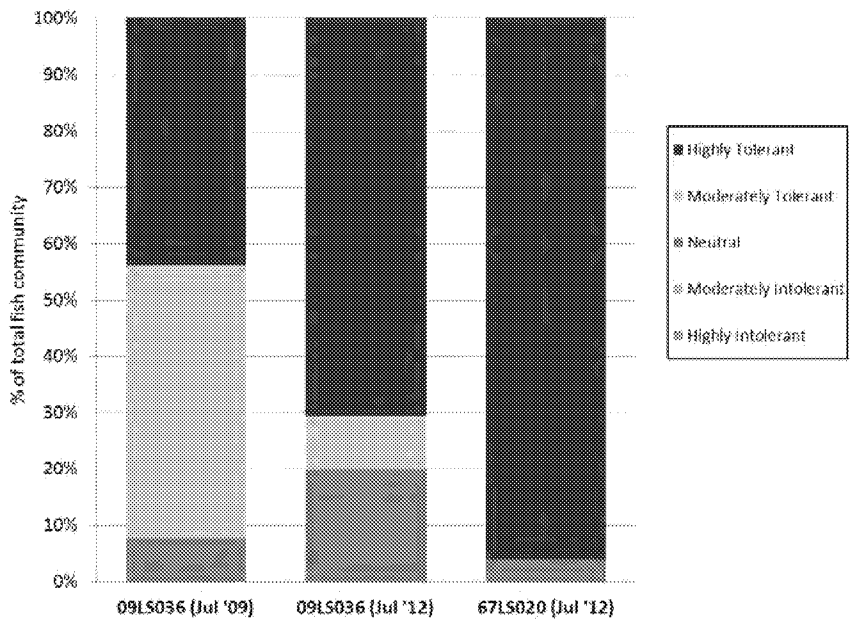
The fish community of Stony Creek is composed primarily of species that are highly tolerant or moderately tolerant of low dissolved oxygen conditions. This is particularly the case at station 67LS020, where 94% of the total fish community was made up of four species that are very tolerant of low DO; central mudminnow (44%), brook stickleback (36%), fathead minnow (8%), and golden shiner (6%). Central mudminnow were also a dominant or abundant species during the two monitoring visits to 09LS036. Several species that can be considered neutral in terms of their tolerance to low DO were observed at 09LS036 (johnny darter, walleye) which suggests that the DO regime at this site may be slightly better for supporting more sensitive species.

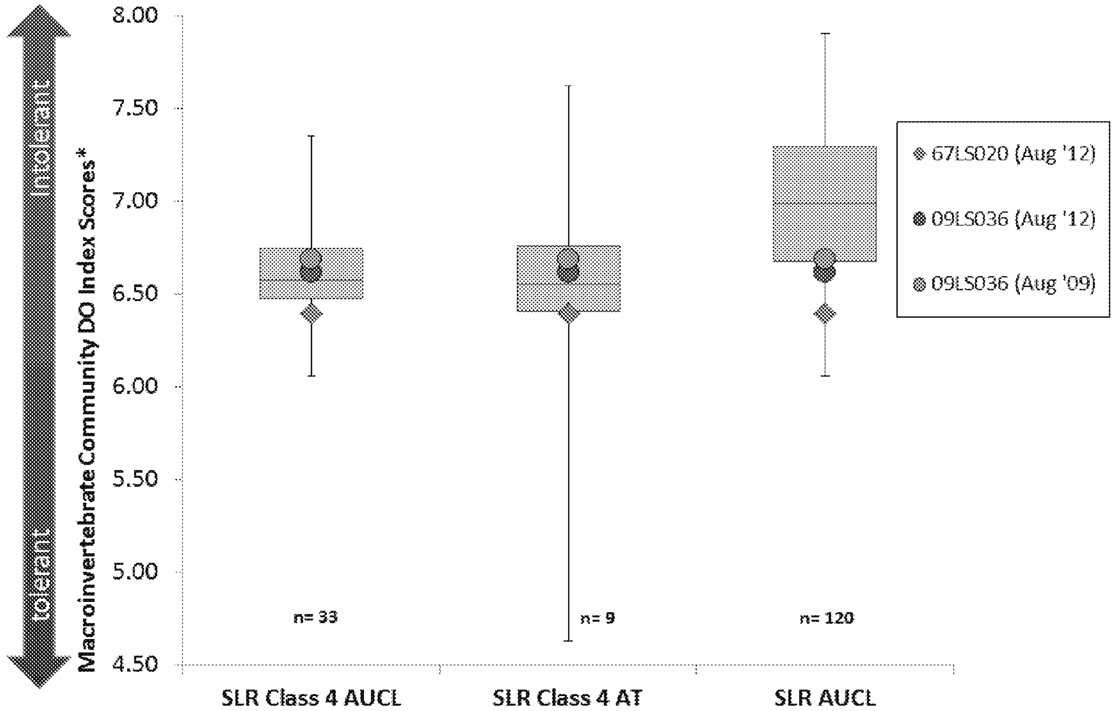
The fish community DO-index values for Stony Creek monitoring sites are poorer than comparable sites with high biological integrity scores (figure BLANK). DO index scores from the 2012 sampling events are particularly low and fall well below the 25th percentile values from the set of reference streams. Clearly, the fish community of Stony Creek is one that is adapted to low dissolved oxygen conditions and lacks the sensitive fish taxa and overall diversity observed in high quality streams of the SLRW with more suitable DO concentrations.

The biological response to low dissolved oxygen concentrations in Stony Creek is not as strong. Several macroinvertebrate taxa considered to be intolerant or moderately intolerant of low DO conditions were observed in small numbers in Stony Creek, including individuals from the genera Neoplasta (member of dance flies family), Maccaffertium (member of flathead mayfly family), and Cheumatopsyche (net-spinning caddisfly family). Individuals from intolerant or moderately intolerant taxa accounted for around 10% of the total community at all three monitoring stations, so although they were present, the majority of the organisms observed at these monitoring stations were not sensitive or intolerant to low DO conditions.

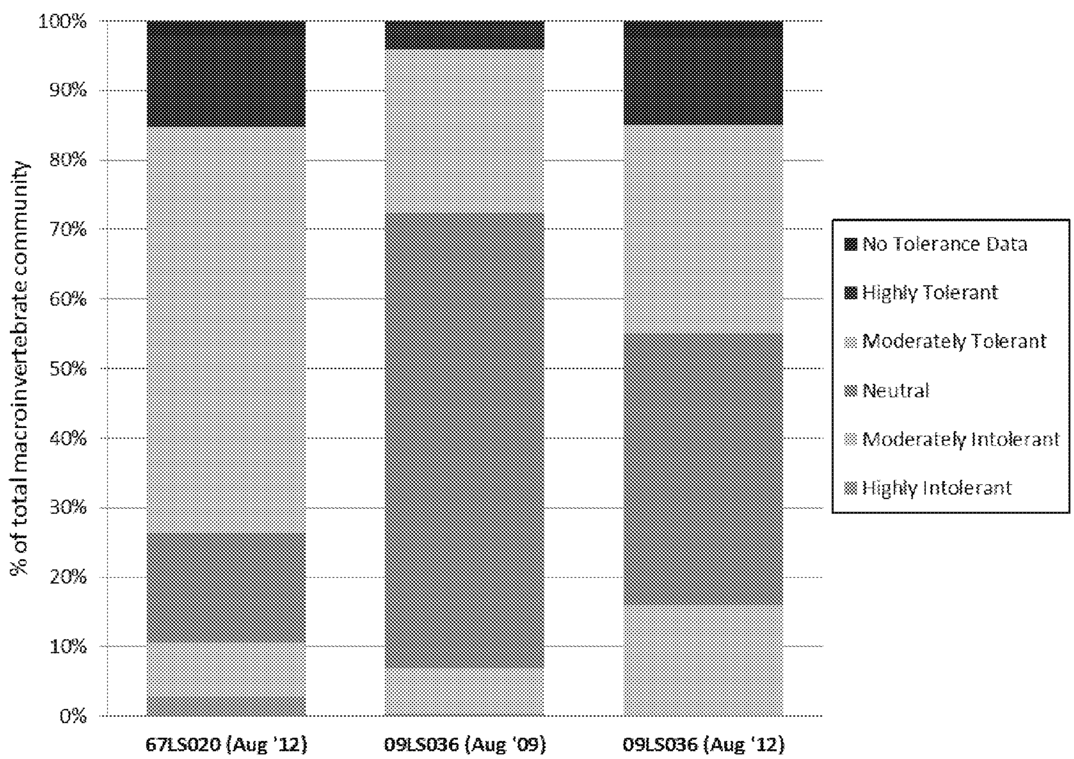
The macroinvertebrate DO index scores for Stony Creek do not provide convincing evidence for or against low dissolved oxygen as a stressor. Index scores for station 09LS036 are slightly better than the median score observed at class 4 SLRW biological monitoring stations scoring above the impairment threshold and upper confidence limit of the impairment threshold. In other words, the macroinvertebrate community at Stony Creek station 09LS036 is not any more adapted to low DO conditions than many of the higher scoring class 4 MIBI stations in the SLRW. The DO index score at station 67LS020 is


Intolerant
Tolerant
Fish Community DO Index Scores*
8.50
8.00
7.50
7.00
6.50
6.00
5.50
5.00
n= 33
n= 50
n= 9
n= 12
n= 120
SLR Class 6 AUCL
SLR Class 6 AT
SLR Class 7 AUCL
SLR Class 7 AT
SLR AUCL
09LS036 (Jul '12)
09LS036 (Jul '09)
67LS020 (Jul '12)


% of total fish community
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
09LS036 (Jul '09)
09LS036 (Jul '12)
67LS020 (Jul '12)
Highly Tolerant
Moderately Tolerant
Neutral
Moderately intolerant
Highly intolerant



Intolerant
tolerant
Macroinvertebrate Community DO Index Scores*
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
n= 33
n= 9
n= 120
SLR Class 4 AUCL
SLR Class 4 AT
SLR AUCL
67LS020 (Aug '12)
09LS036 (Aug '12)
09LS036 (Aug '09)



% of total macroinvertebrate community
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
67LS020 (Aug '12)
09LS036 (Aug '09)
09LS036 (Aug '12)
No Tolerance Data
Highly Tolerant
Moderately Tolerant
Neutral
Moderately Intolerant
Highly Intolerant

Total Suspended Solids and Stream Transparency

Stream transparency and TSS data for Stony Creek indicate that this system is carrying more sediment than other streams in the region. TSS data for Stony Creek are somewhat limited, with one exeedence of the WQ threshold in six sampling events (16.7%). Stream transparency data are somewhat more robust, with 13 total observations and a 23.1% exceedence rate of the WQ threshold. The maximum transparency reading on Stony Creek is 51 cm, which is considerably lower than the rest of the impaired streams in this watershed zone. All of the other impaired streams had transparency values of 100 cm or more. Stony Creek is typically more severely tannin stained than other streams in the MDW-PB, which likely limits transparency values even during lower flows.

The stream channel of Stony Creek shows signs of lateral migration, which may be leading to increased sediment loadings. Irregular meanders with oxbows and oxbow cutoffs dominate the lower reaches of Stony Creek where the fish and invertebrate impairment is located. This meander pattern is an indicator of lateral instability (Rosgen, 2006).

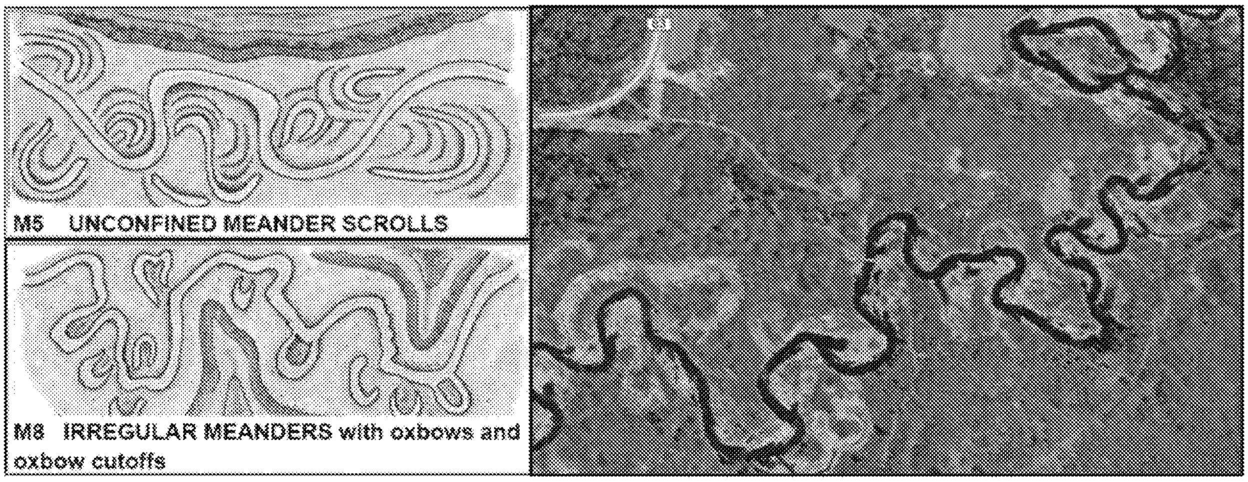


Figure BLANK: (Left) Meander patterns that apply to Stony Creek (from Rosgen 2006). **(Right)** Aerial photo of Stony Creek showing irregular meander pattern, oxbows, and oxbow cutoffs (see upper right of photo for large oxbow cutoff)

{Insert Sources and Pathways}

<u>Fish Response to TSS</u>

The fish IBI impairment on Stony Creek is the result of poor metrics scores related to low fish counts and a lack of species that are expected in healthy headwaters streams (minnow sp., darters, sculpins). In the 1967 sample of station 67LS020, nearly half of the fish observed were taxa that are considered highly intolerant or moderately intolerant of elevated TSS concentrations. A healthy population of longnose dace, and a small number of mottled sculpin accounted for this observation. In addition, this sample lacked fish taxa that can be considered tolerant or highly tolerant of TSS. Fish data collected at the same station in 2012 shows a community shift to one that is more tolerant of TSS (figure BLANK). Longnose dace and mottled sculpin were not observed in the 2012 sample, and more tolerant species such as fathead minnow and brook stickleback were observed in their place. Central mudminnow and brook stickleback accounted for nearly 80% of the fish assemblage in 2012. There is no long term record of TSS concentrations or turbidity levels for Stony Creek that can be linked to this fish assemblage change, but clearly, the current fish community is more tolerant of TSS (and other stressors) than the community observed in the late 1960's.

Fish data from the other biological monitoring station on Stony Creek (09LS036) were only collected in 2009 and 2012. A small population of pearl dace, and a single burbot individual were observed, which accounted for the only TSS intolerant species observed at this station. Fish taxa that were prominent in these samples include central mudminnow, johnny darter, and white sucker. A small population of fish taxa that are tolerant of TSS (green sunfish and black bullhead) also showed up in the sample, but the overall fish community at this station can be considered neither tolerant nor intolerant of TSS.

Invert Response to TSS

Stony Creek was listed as impaired for failing to meet the MIBI criteria at both monitoring stations (67LS020 and 09LS036). Low relative abundance of collector-filterer taxa and a lack of pollution intolerant taxa were two of the primary metrics that contributed to the low MIBI scores at these stations. Both of these metrics have the potential to be negatively influenced by elevated TSS concentrations. Collecter-filterer taxa, which obtain food by filtering particles from the water column, have shown to respond negatively to increases in TSS in streams and rivers of northern Minnesota (Markus, 2011). Non-hydropsychid caddisfly taxa were present in relatively low numbers in Stony Creek, which is potentially another measure that has shown a negative response to TSS in streams of northern Minnesota.

The macroinvertebrate community in Stony Creek is more tolerant of TSS in comparison to high quality stations of the same MIBI class. The box plots in figure BLANK compare data for a series of TSS related metrics between Stony Creek monitoring stations and class 4 stations that scored above the upper confidence limit of the MIBI threshold (class 4 MIBI AUCL). In both sampling visits to 09LS036, over half of the macroinvertebrate taxa observed are considered tolerant of TSS (figure BLANK). Both of the Stony Creek monitoring stations exceed 75th percentile values (or greater) for measures of % TSS tolerant and %TSS very tolerant (figure BLANK). TSS index scores, which are a composite value of taxa tolerance and relative abundance measures, are clearly showing that the invertebrate assemblage of Stony Creek re more tolerant of TSS than the class 4 MIBI AUCL stations (figure BLANK).

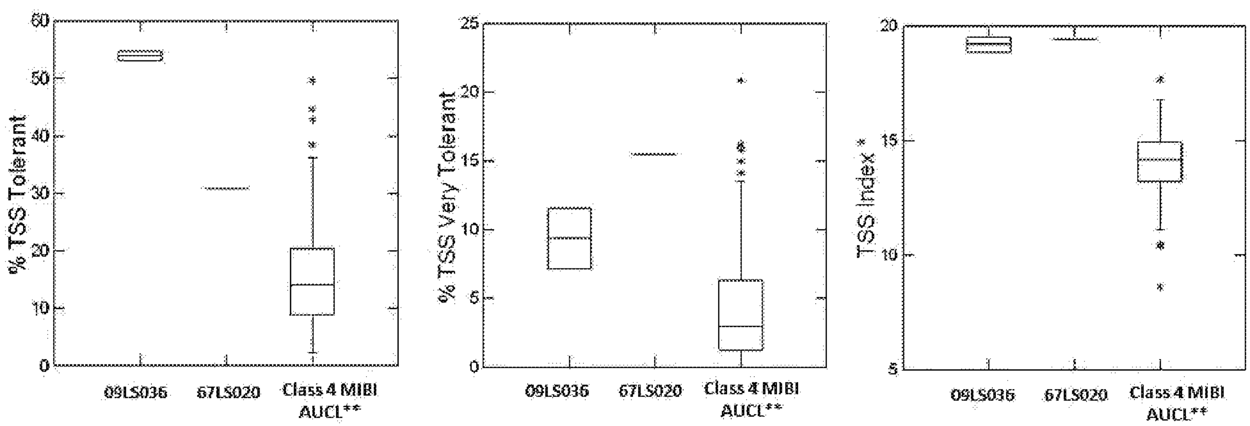


Figure BLANK: class 4 MIBI AUCL (n=120)

Summary:

TSS concentrations in Stony Creek show minor exceedences of the WQS, and transparency data also indicate that water clarity in this system is lower than other streams in this region of the SLRW watershed. However, TSS and transparency data are not indicative of severely poor conditions for aquatic life, as most of the exceedences of WQS were minor and the rate of exceedence is not extremely high (16.7% for TSS and 23.1% for transparency).

The stressor-response relationship between TSS and the fish community of Stony Creek is somewhat unclear and does not provide convincing evidence in support of TSS as a cause of impairment. Most of the fish observed in Stony Creek are neither tolerant nor intolerant of elevated TSS concentrations. On the other hand, the macroinvertebrate data does show a community that is generally tolerant of elevated TSS concentrations at both monitoring locations. It is possible that this same set of macroinvertebrate taxa are tolerant of other stressors as well (low dissolved oxygen, habitat degradation). This calls into play the importance of other pieces of evidence when evaluating TSS as a stressor, in particular, the water chemistry data.

Despite some evidence in support of TSS as a cause of macroinvertebrate impairment in Stony Creek, the water quality component of the data set is should be improved upon before TSS is considered a stressor.

Water Quality Overview: TSS and Transparency

Elevated total suspended solids (TSS) concentrations was identified as a candidate cause for impairment in the MDW-PB based on the screening level assessment performed in section BLANK. TSS concentrations observed in the impaired streams of the MDW-PB are not exceptionally high (Max = 30 mg/L, Little Swan Creek on 4/30/13), and are not capable of causing acute stress to aquatic life. However, available data does show minor exceedences of water quality standards and the potential for chronic stress related to elevated TSS. In addition to TSS results, stream transparency data will also be utilized to evaluate this stressor. Stream transparency has been shown to be positively correlated with TSS (source), but also provides a measure of other factors that can potentially limit water clarity (tannin stain, organics). Many of the streams in the MDW-PB watershed are heavily tannin stained and have low transparency readings throughout the year.

Available TSS and transparency data for these streams are summarized in figures BLANK and BLANK. TSS data for several of these streams are limited in number and somewhat biased towards high flow events. As a result, the data available for some streams may not be representative of conditions that aquatic life are exposed to for long durations. Taking both the TSS and transparency data into account, there is considerable evidence to eliminate TSS as a candidate cause for impairment in Skunk Creek, Vaara Creek, and the St. Louis River. None of these impaired reaches have TSS or transparency data that violate WQ standards. Although these streams are heavily tannin stained, maximum transparency values equal or exceed 100 cm (figure BLANK). Biological data from these streams (discussed in the following sections) also provides further evidence against TSS as a stressor for these impairments.

TSS concentrations exceeding WQ standards have been recorded in Little Swan Creek, Stony Creek, Sand Creek, and Unnamed Tributary to St. Louis River.

Biological Response to TSS: Overview of Watershed Zone Conditions

Logistic regression model results from Vaara Creek, Skunk Creek, and site 09LS036 on Stony Creek all show a high probability of meeting the WQS for TSS based on the fish taxa observed at those locations (figure BLANK). These streams support fish species that are typically not observed in turbid water such, as burbot, pearl dace, and mottled sculpin. Model results for Sand Creek, and station 67LS020 on Stony Creek show a slightly higher likelihood of TSS stress than other sites in the watershed zone. Although the model results show slightly lower poorer conditions at these locations, the probability of meeting the TSS standard is still greater than 70%.

Based on these model results and available water chemistry data, TSS can be eliminated as a cause of fish impairment in Skunk Creek and Vaara Creek. Model results and water chemistry data for Stony Creek and Sand Creek are less convincing, and these streams will be evaluated further in the following section. Logistic regression model results are not available for Little Swan Creek, as the analysis did not include coldwater trout streams. Therefore, this stream will also be evaluated further.

Figure BLANK:

Biological Monitoring Station	Stream Name	Probability_TSSRA*
97LS034	Vaara Creek	0.89
09LS036	Stony Creek	0.86
09LS036	Stony Creek	0.85
97LS034	Vaara Creek	0.85
09LS031	Skunk Creek	0.83
67LS020	Stony Creek	0.74
09LS033	Sand Creek	0.70

* estimated probability of achieving a "meets standard" assessment for TSS (e.g. 0.70 = 70% chance that station will meet TSS water quality standard based on fish assemblage data)

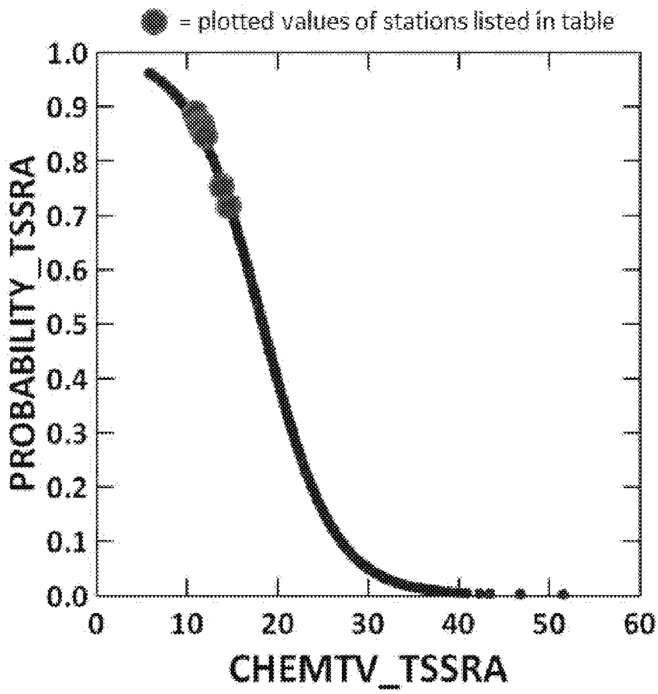


Figure BLANK:

a. TSS / Turbidity
b. pH / Low Ionic Strength
c. Habitat

Unnamed Trib to St. Louis River

d. Habitat
e. Dissolved Oxygen
f. pH / Low Ionic Strength

Little Swan Creek

Temperature

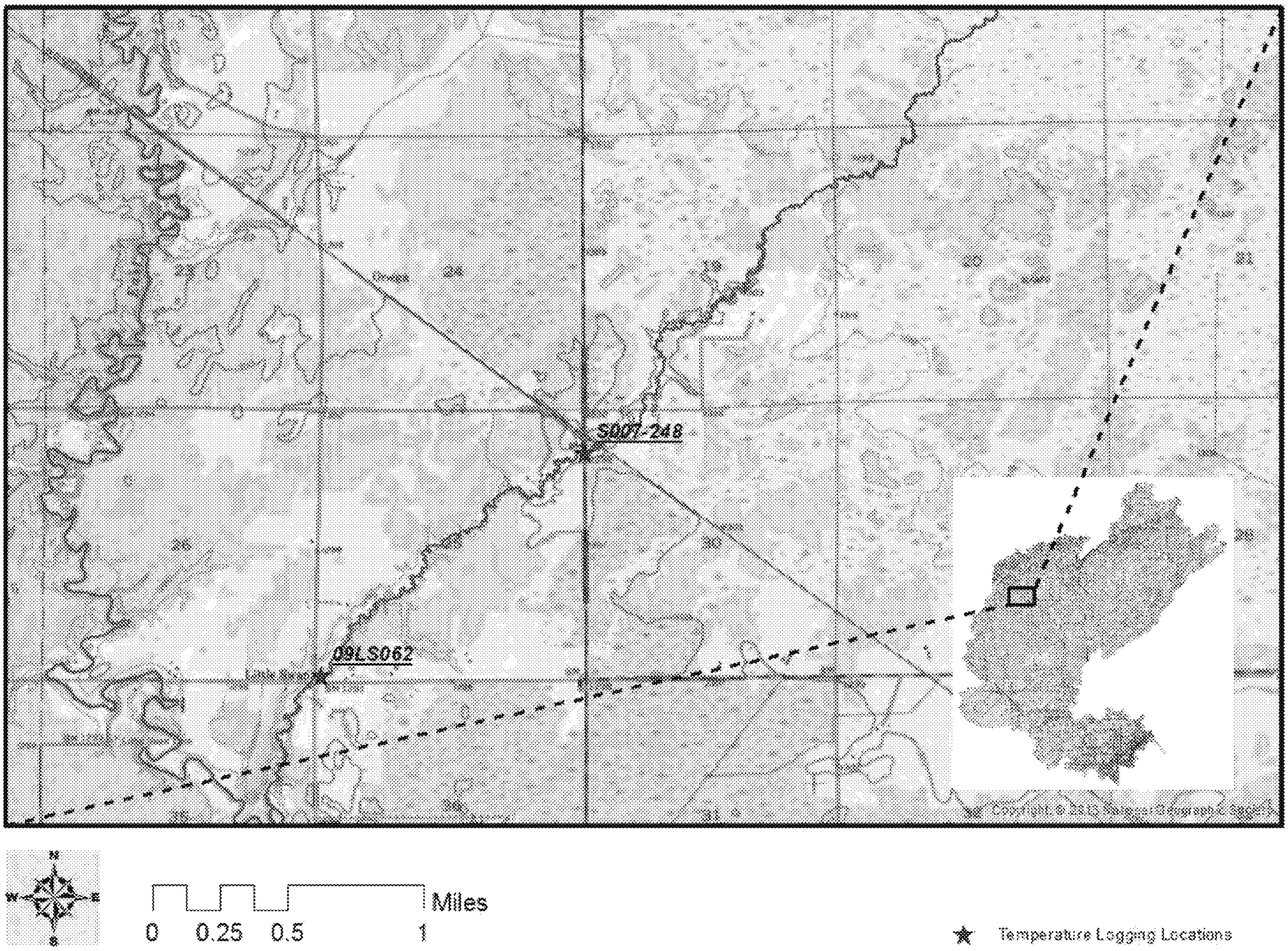
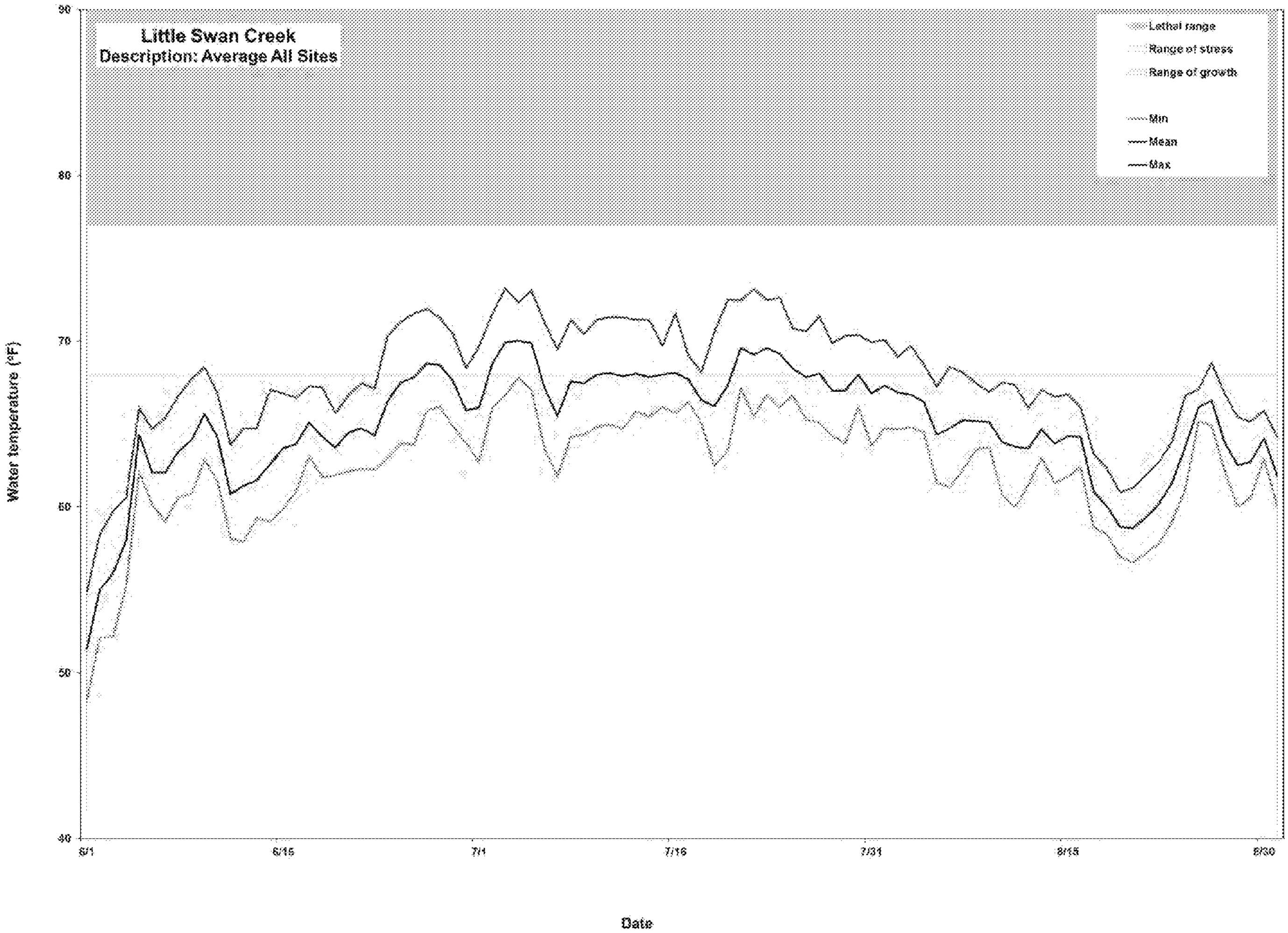


Figure X: HOBO logger locations on Little Swan Creek

We have temperature data from two sites on Little Swan Creek: S007-248 at CR 5 (2012) and 09LS062 at CR 444 (2009 and 2012). Only data between June 1 and August 31 were analyzed – when stream temperatures are most likely to exceed the stress threshold for brook trout and other cold water fish species.

The average daily temperature for the most part stayed in the range of growth throughout the summer. Daily maximums well exceeded the stress threshold from the end of June to the beginning of August.



Little Swan Creek
Description: Average All Sites
Lethal range
Range of stress
Range of growth
Min
Mean
Max
Water temperature (°F)
90
80
70
60
50
40
6/1
6/16
7/1
7/16
7/31
8/15
8/30
Date

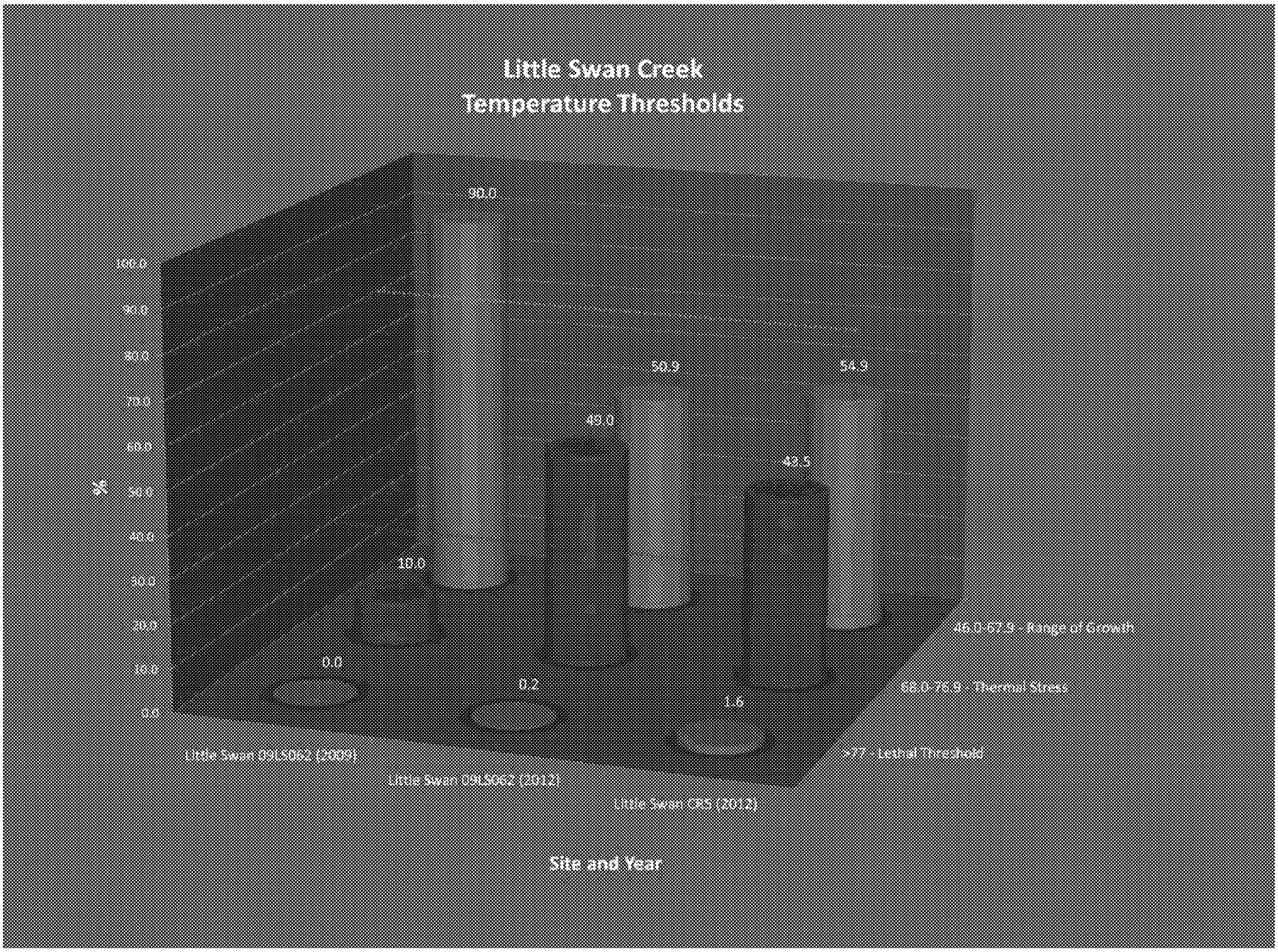


Figure X: Percentage of time spent in BKT growth, stress and lethal ranges

Little Swan Creek shows susceptibility to ambient atmospheric conditions. In 2009, a colder-than-normal year, the stream at 09LS062 had excellent cold water. Only 10% of the summer was spent in the stress range for brook trout. Summer temperatures in nearby Hibbing, MN that year were 4.8°F below average (weather-warehouse.com). In contrast, at that same site during the warmer-than-normal summer of 2012 the stream was in the stress range nearly 50% of the time. At 09LS062 the stream once stayed above the brook trout stress threshold for 8 straight days. That year summer temperatures were about 0.8°F above average. The summer air temperatures in 2012 were much closer to average than 2009, suggesting that 2009 was an anomaly and the stream temperatures in 2012 are much more reflective of an average summer for Little Swan Creek.

Such a strong mirroring of atmospheric conditions implies that 1) there is poor groundwater input in the system and/or 2) there is very little shading for the stream, leaving it vulnerable to heat loading from the sun. The watershed is low-gradient, has not been heavily ditched and road densities are low relative to others in the Meadowlands watershed zone. The riparian corridor is rather healthy as well, with moderate amounts of larger trees and long grasses to provide shade for most of the length of the stream (see Figure X).However, large-scale logging activities in the upper part of the watershed (as evidenced by historic photo analysis) and the underlying geology of the watershed may be unfavorable to groundwater recharge (Lindgren ,et al., 2006, *A Study of the St. Louis River*, MN DNR Section of Fisheries). More study is needed to ascertain the impact of ground water recharge (or lack thereof) on stream temperature. Another potential source of temperature loading is beaver activity. Using LiDAR profiles and high-resolution aerial photos, 6 beaver dams were counted on 7.2 miles of Little Swan Creek (0.8 dams/mile). One especially large, meter-high dam in the upper reaches has created a half-mile long impoundment. In contrast, East Swan Creek at 09LS064 in 2012, just four miles away, has healthy stream temperatures (80% growth range) and very little beaver activity. It is likely that the beaver activity on Little Swan Creek is having a negative impact on stream temperature and making the stream much more susceptible to the ambient atmospheric conditions. Regardless of the cause, there is little doubt that cold water fish species are being stressed by high temperatures and high temperature fluctuations (Figure X).

Figure X: Long grasses and deciduous tree canopies dominate the riparian corridor for Little Swan Creek

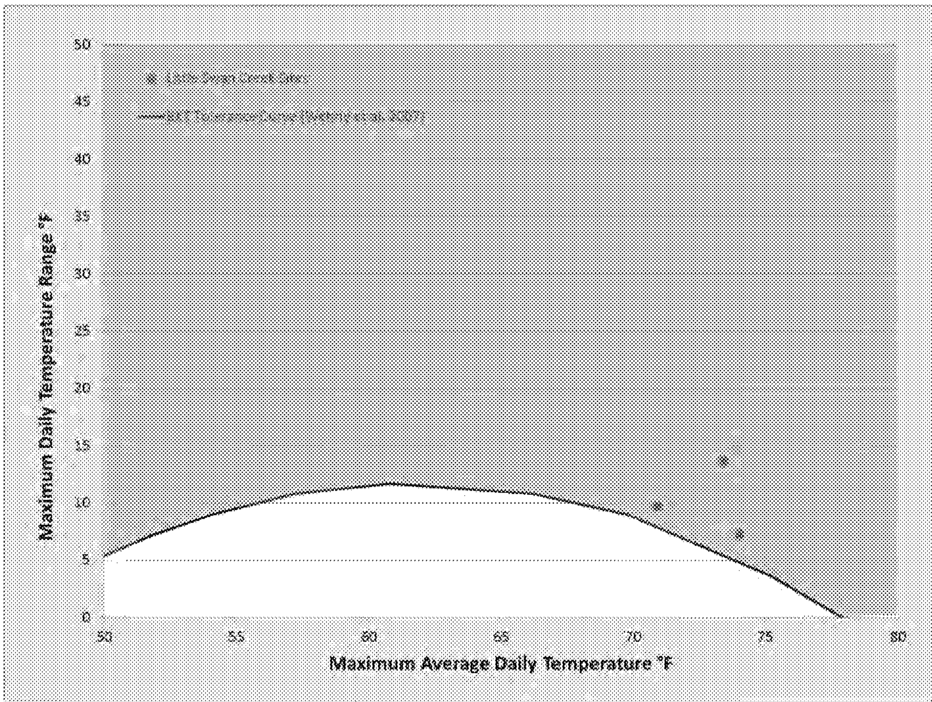


Figure X: Maximum daily temperature and maximum temperature fluctuation recorded on Little Swan Creek

Visit Number	Waterbody Name	Field Number	Fish Class	Fish IBI	Coldwater Taxa Present	Coldwater Intolerant %	Coldwater Sensitive Taxa %
20091060	Little Swan Creek	09LS062	11	34	0	0.00	0.00
				Average	0	0.00	0.00

	Visit Number	Waterbody Name	Field Number	Fish Class	Fish IBI	Coldwater Taxa Present	Coldwater Intolerant %	Coldwater Sensitive Taxa %
Unimpaired Sites	20091057	Dutch Slough	09LS014	11	49	1	9.09	40.00
	20091147	Hay Creek	97LS108	11	71	2	51.49	42.86
	20091156	Keene Creek	95LS028	11	61	1	27.47	25.00
	20091146	Little Otter Creek	09LS116	11	51	2	2.33	30.00
	20091012	Midway River	09LS117	11	55	2	15.43	30.77
	20091013	Midway River	09LS118	11	61	3	15.71	35.71
	20091068	Midway River	09LS117	11	59	2	23.44	30.77
	20091037	Pine River	09LS013	11	50	2	5.42	22.73
	20091065	Pine River	09LS013	11	53	2	1.78	31.25
	19970052	Trib. to Midway River	97LS039	11	63	2	2.74	57.14
	20091153	Trib. to Midway River	97LS112	11	52	1	23.38	44.44
	19970087	White Pine River	97LS083	11	63	2	15.55	38.46
	20091148	White Pine River	09LS115	11	55	1	5.88	28.57
					Average	1.8	15.36	35.21

Figure X: Coldwater metrics of Little Swan Creek and unimpaired coldwater streams in the St. Louis River watershed

An analysis of coldwater biological metrics reaffirms temperature as a stressor compared with unimpaired coldwater sites in the St. Louis River watershed. No coldwater taxa were sampled in the reportable visit to Little Swan biosite 09LS062 (Table X). In contrast, the numbers for the unimpaired coldwater biosites are 1.8, 15.36% and 35.21%, respectively.

Restoration/Protection Strategies to Reduce Water Temperatures

1. Beaver and beaver dam removal from the lower gradient reaches of the stream would have positive results in terms of water temperature, as well as spawning habitat, dissolved oxygen, connectivity, and decreased populations of non-trout fish that compete with brook trout for food.
2. An assessment is needed to find out whether increased runoff and decreased groundwater recharge due to logging activity is having an impact on stream temperature
3. A geomorphic assessment of the Little Swan Creek watershed is needed to investigate whether some reaches have unstable dimensions and high width/depth ratios. If that is the case, restoration projects could be completed that would narrow the stream and decrease the amount of temperature loading from the atmosphere.

Dissolved Oxygen

TSS / Turbidity

Little Swan Creek

Little Swan Creek, a coldwater tributary to the East Swan River, is listed as impaired for failing to meet the coldwater fish IBI criteria. The lone biological monitoring station on this stream (09LS062) scored poorly in the fish IBI due to a lack coldwater species and a high percentage of omnivorous fish taxa, which are typically uncommon in functioning coldwater streams. Overall taxa richness and fish abundance were both relatively low (5 species, 34 total fish). White sucker accounted for nearly 60% of the individuals sampled at the lone monitoring station on Little Swan Creek. Also present in the sample were trout-perch (18%), creek chub (12%), central mudminnow (9%), and northern pike (3%).

None of the fish taxa observed in Little Swan Creek are considered to be strongly associated with elevated TSS concentrations. The entire fish community at 09LS062 can be considered "neutral" in terms of tolerance level to elevated TSS, meaning that they are neither tolerant nor intolerant of this stressor (figure blank). White sucker, the most dominant taxa on Little Swan Creek, is the most common and widespread sucker species in Minnesota (Phillips et al., 1982) and is able to adapt to a variety of environmental conditions. The other fish taxa observed in Little Swan Creek possess a similar ability to adapt to different stream conditions and their presence does not offer a strong biological indicator for TSS induced stress.

Little Swan Creek is not currently listed as impaired for macroinvertebrate IBI, however, the data can be evaluated as another piece of evidence for or against TSS as a stressor. Macroinvertebrate taxa that are considered to be "tolerant" or "very tolerant" accounted for a very small percentage of the overall population (4.0% and 2.6%, respectively) at the lone monitoring station on this stream. Although fish and invertebrates have different tolerance levels and responses to suspended sediment, the low percentages of TSS tolerant invertebrate taxa is another piece of evidence that weakens the case for TSS as a stressor.

Summary:

Elevated TSS concentrations in Little Swan Creek are limited to high flow periods during snowmelt and following significant rain events. The only significant exceedence of the 10 mg/L WQS occurred during an April 2013 snowmelt sampling event, when TSS concentration in the stream were 30 mg/L. The other four exceedences of the WQS ranged from 11-17 mg/L. Although TSS concentrations in Little Swan Creek are slightly elevated compared to other streams in the region, it is likely that the thermal and dissolved oxygen regime of this system are more significant stressors limiting coldwater fish populations (see section BLANK and BLANK). TSS is not considered a stressor to aquatic life in Little Swan Creek.

g. Low Ionic Strength / pH
h. Habitat

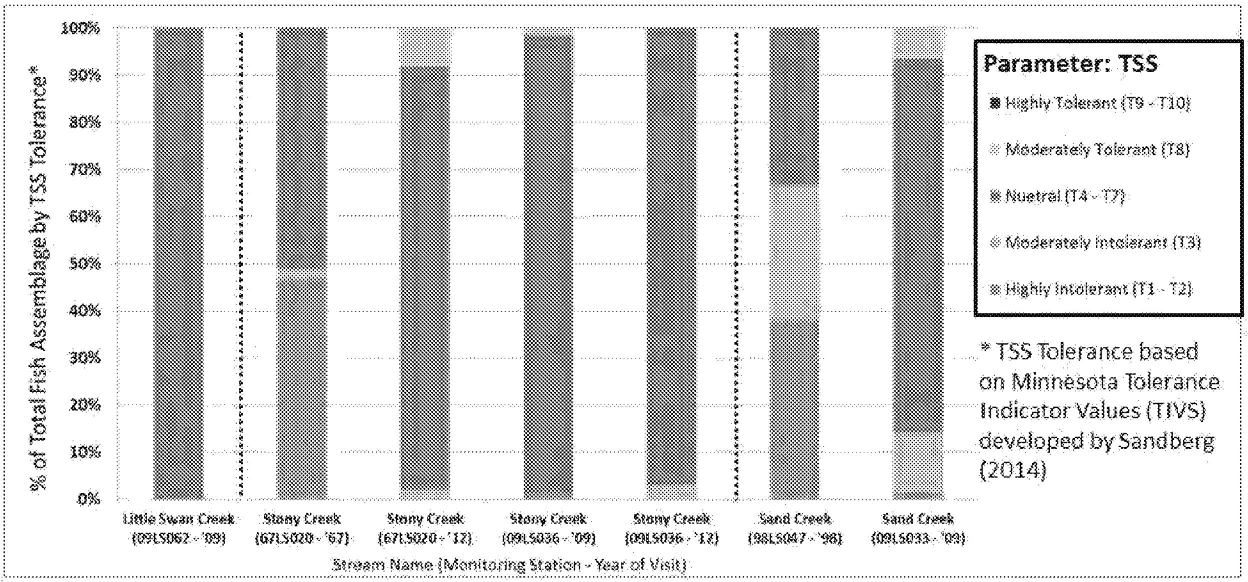


Figure BLANK:

STRENGTH OF EVIDENCE (SOE) TABLE	Stony Creek			
Spatial/temporal co-occurrence				
Temporal sequence				
Causal pathway				
Evidence of exposure, biological mechanism				
Field experiments /manipulation of exposure				

Laboratory analysis of site media				
Verified or tested predictions				
Symptoms				
Mechanistically plausible cause				
Stressor-response in other lab studies				
Stressor-response in other field studies				
Stressor-response in ecological models				
Manipulation experiments at other sites				
Analogous stressors				
Consistency of evidence				
Explanatory power of evidence				

Makinen Lakes Watershed Zone

Impaired streams in this watershed zone include Water Hen Creek, Water Hen River, and Paleface Creek. All of these streams are low gradient and feature predominantly glide-pool habitats. This watershed zone contains numerous lakes and wetlands, and most of the streams within it are connected to these features. Generally, the lakes of area are in relatively good condition. However, several of the lakes that are hydrologically connected to the impaired streams are impacted by elevated phosphorous concentrations. The outlet of Dingham Lake, which is impaired for excess phosphorous, enters Paleface Creek just upstream from the impaired reach of that stream and nutrient-impaired Long Lake serves as the headwaters of Water Hen River.

Figure BLANK

Symptoms of macroinvertebrate impairment were very similar in all of the impaired streams of this watershed zone. At impaired sites, the macroinvertebrate communities tend to be dominated by non-insect taxa. Freshwater amphipods from the genus Hyallela were very abundant, particularly in the impaired reach of Water Hen River. Members of the genus Hyallela are generally tolerant of disturbance and are important in the breakdown of organic matter in streams and rivers (Bouchard Jr., 2004). Aquatic worms (Oligochaeta), snails (Physa, Hydrobiidae, and Planorbidae), and non-biting midges (Ablabesmia, Tanytarsus, Cricotopus) were also dominant in samples collected from these streams. Aquatic insect taxa were not abundant or diverse at these locations. The insect taxa present were well-adapted for living in slow-moving or stagnant streams with wetland qualities, and included narrow-winged damselflies (Coenagrionidae), small minnow mayflies (Baetidae), and prong-gilled mayflies (Leptophlebiidae).

Paleface Creek is the only stream impaired for low fish IBI in this watershed zone. The fish community in this stream is extremely limited in terms of species diversity and overall fish abundance. Only six species of fish were observed in two sampling visits to this stream; black bullhead, central mudminnow, tadpole madtom, white sucker, northern pike, and pumpkinseed sunfish. Central mudminnow individuals accounted for 83% and 66% of the total fish counted during the sampling visits. This fish assemblage is typical of a low gradient stream with significant wetland influence. Extremely low dissolved oxygen values were observed in Paleface Creek throughout most of the open-water season (April – November).

Water Hen Creek / Water Hen River

Dissolved Oxygen

Sources and Pathways Contributing to Low Dissolved Oxygen

Wetlands

Wetlands are a prominent land cover type found in watersheds of Water Hen Creek, Water Hen River, and Mud Hen Creek (figure BLANK). Many of the wetland areas in these watersheds are expansive, poorly drained areas with hydric peat soil classifications. Hydric soils are permanently or seasonally saturated by water, resulting in anaerobic conditions. The entire impaired reach of Water Hen Creek, from Long Lake to its confluence with Mud Hen Creek, is bordered by a wetland dominated riparian corridor with partially hydric or all hydric soil classifications (figure BLANK). Hydric peat soils are particularly abundant and concentrated in the lower portion of the Water Hen Creek watershed. A large wetland complex with hydric peat soil type is located just upstream and adjacent to the lower impaired reach. It is likely that this wetland complex is delivering anoxic water to this reach of Water Hen Creek.

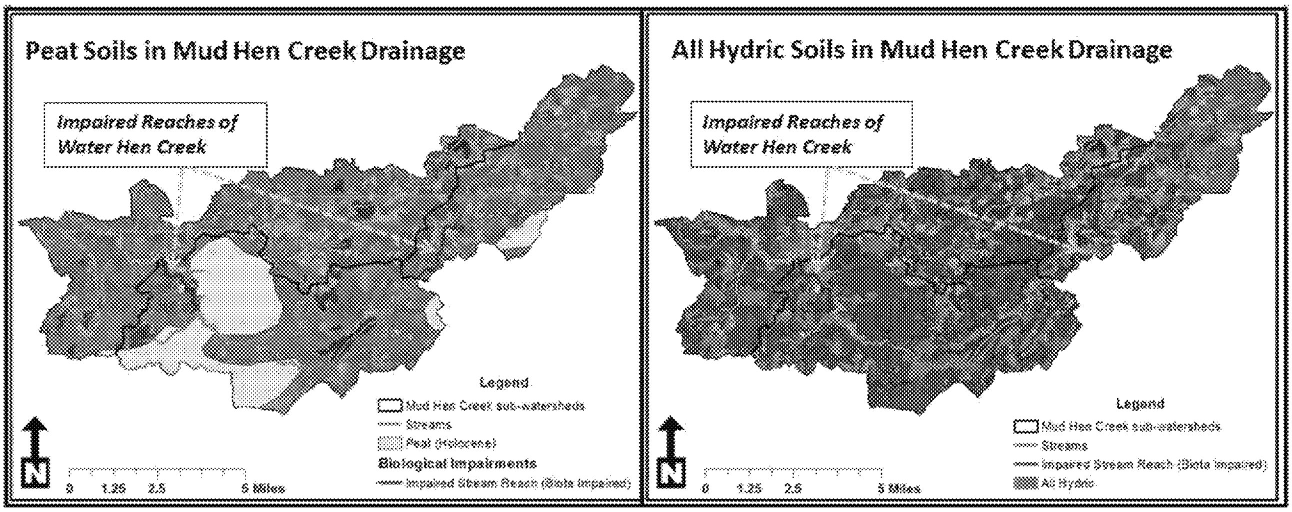


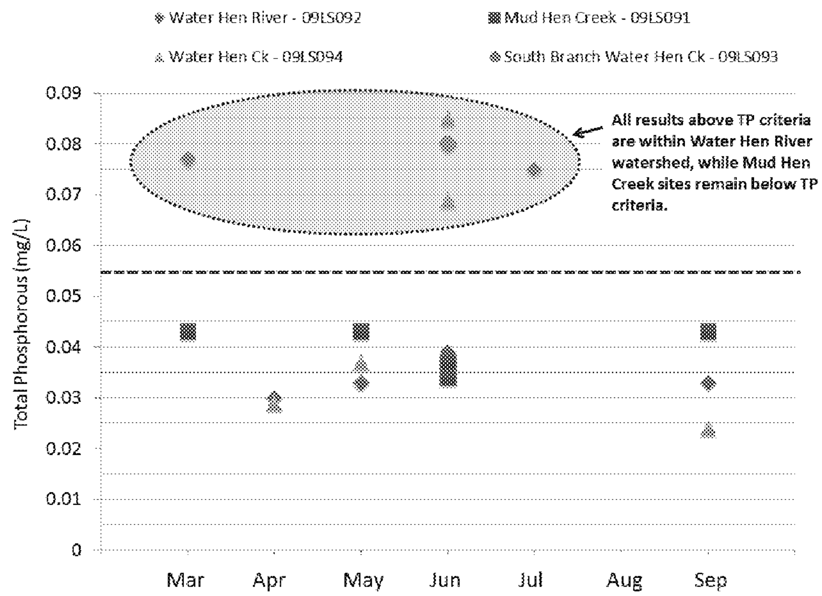
Figure BLANK:

Nutrients and Productivity

Total phosphorous (TP) concentrations in Water Hen Creek are slightly elevated and occasionally exceed river nutrient criteria of 0.055 mg/L (figure BLANK). Several of the elevated TP results on record have occurred during major runoff events or immediately after these events. These elevated TP results may be related to the flushing of nutrient rich wetlands and/or lakes in the watershed. However, elevated TP concentrations have also occurred during lower flows in Water Hen Creek and tributary streams. Samples collected at biological monitoring stations 09LS092 and 09LS093 during low flows resulted in TP concentrations of 0.075 mg/L and 0.080 mg/L, respectively. Based on the available data, TP concentrations in Water Hen Creek are generally higher than Mud Hen Creek, possibly due to the greater wetland presence in the Water Hen Creek drainage.

Nutrient-impaired lakes are another potential source of TP in this watershed. Water Hen Creek flows through Long Lake (impaired for excess nutrients), which may result in higher nutrient concentrations in the lower reaches of the creek during certain times of the year. The TP data available are insufficient for evaluating the effects of Long Lake on the nutrient dynamics of lower Water Hen Creek.

Despite elevated TP concentrations, dissolved oxygen flux in Water Hen Creek is typically low (0.5 – 2 mg/L). The tannin stained water of this stream may limit sunlight penetration and reduce primary productivity. Low DO flux in streams with wetland dominated watersheds and tannin stained water is a common observation in the SLRW.



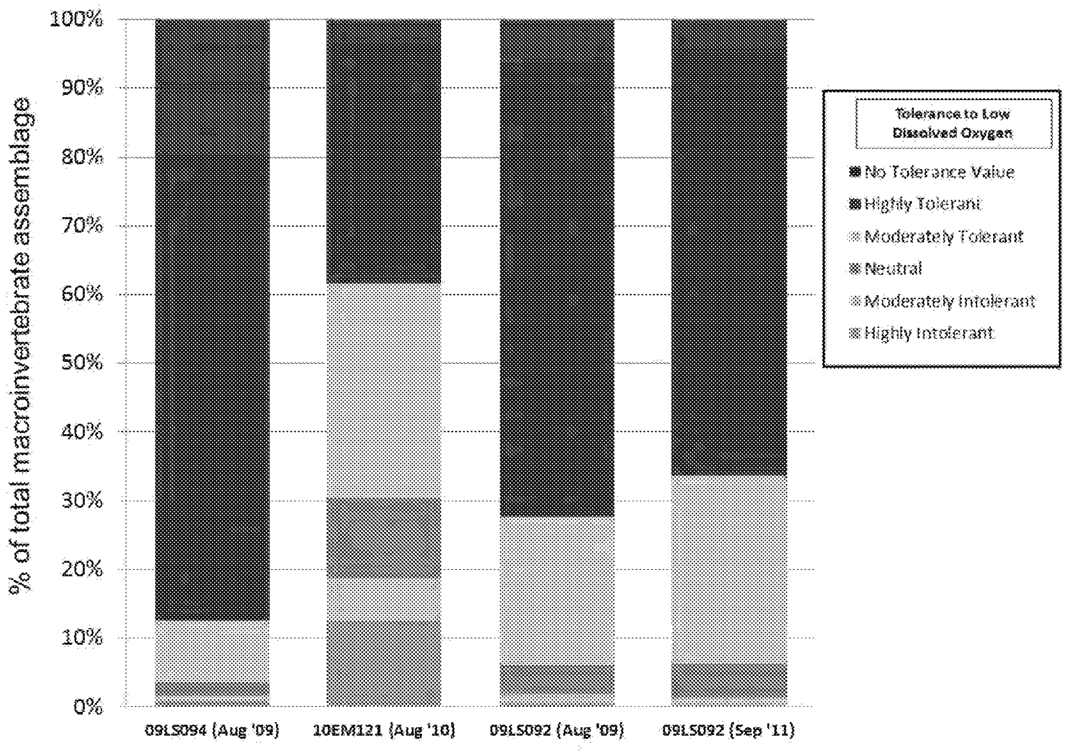
Biological Response to Low Dissolved Oxygen

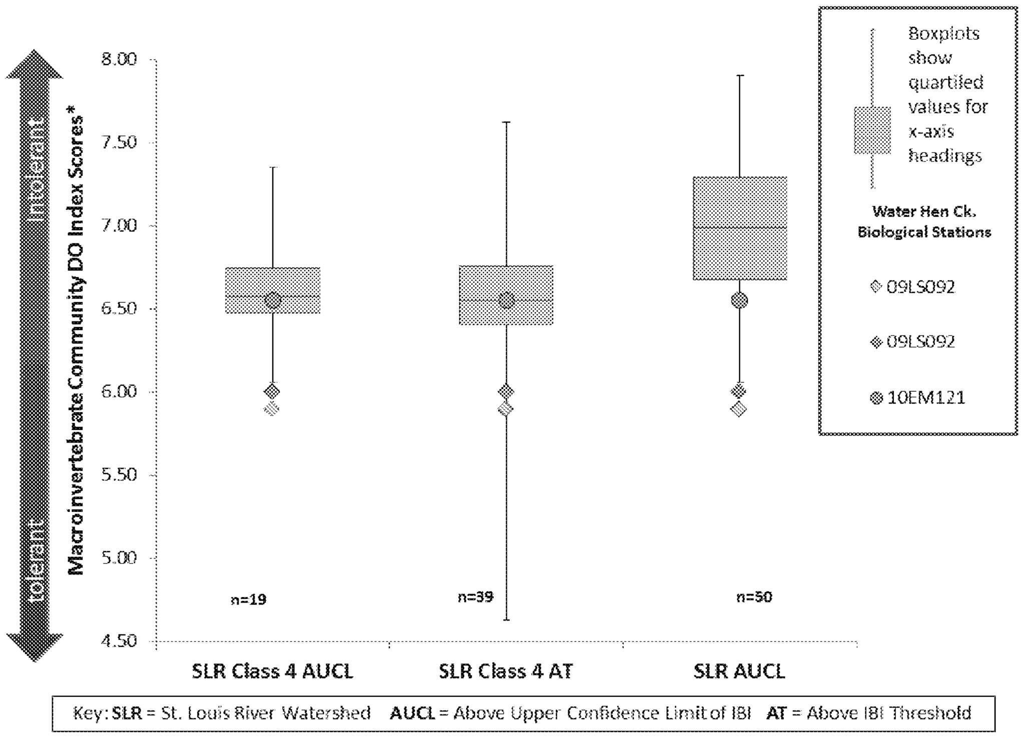
The impaired reaches of Water Hen Creek and Water Hen River are both dominated by macroinvertebrate taxa that are tolerant of low dissolved oxygen conditions (Figure BLANK). Between 66% and 89% of the individuals sampled from these reaches are either moderately or highly tolerant of low dissolved oxygen. The amphipod *Hyallela* was the most abundant taxon at all monitoring stations. These organisms are considered highly tolerant of low dissolved oxygen concentrations among other stressors (nutrient enrichment, poor physical habitat). Freshwater snails from the genera *Ferrissia*, *Planorbidae*, *Physa*, which are also known to tolerate low DO concentrations, were also common within the impaired segments of these two streams.

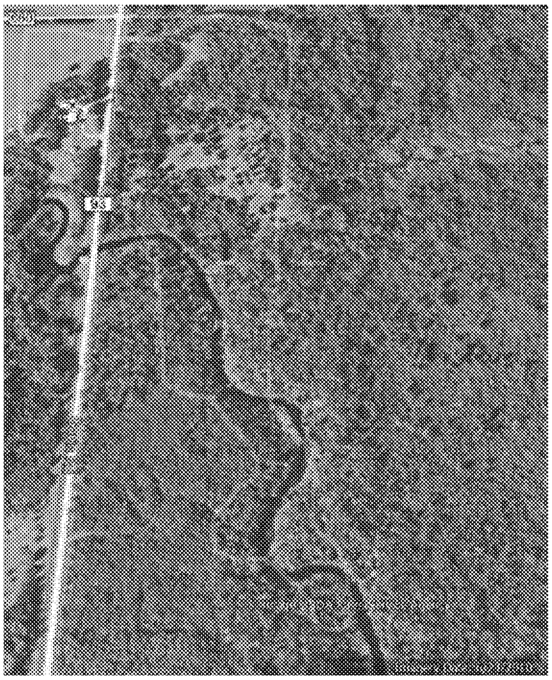
While the majority of the macroinvertebrate data indicates a community that is tolerant of low DO, there is one reach of Water Hen Creek that displayed more DO sensitive macroinvertebrate community. The macroinvertebrate community at station 10EM121 appears to be somewhat less tolerant of low dissolved oxygen. Four macroinvertebrate taxa that are sensitive to low dissolved oxygen levels were observed at this station. Nearly 20% of the individual organisms sampled at this location belong to taxa that are sensitive to low DO. Still, over 50% of the organisms at this station can be considered moderately or highly tolerant of low DO conditions (figure BLANK).

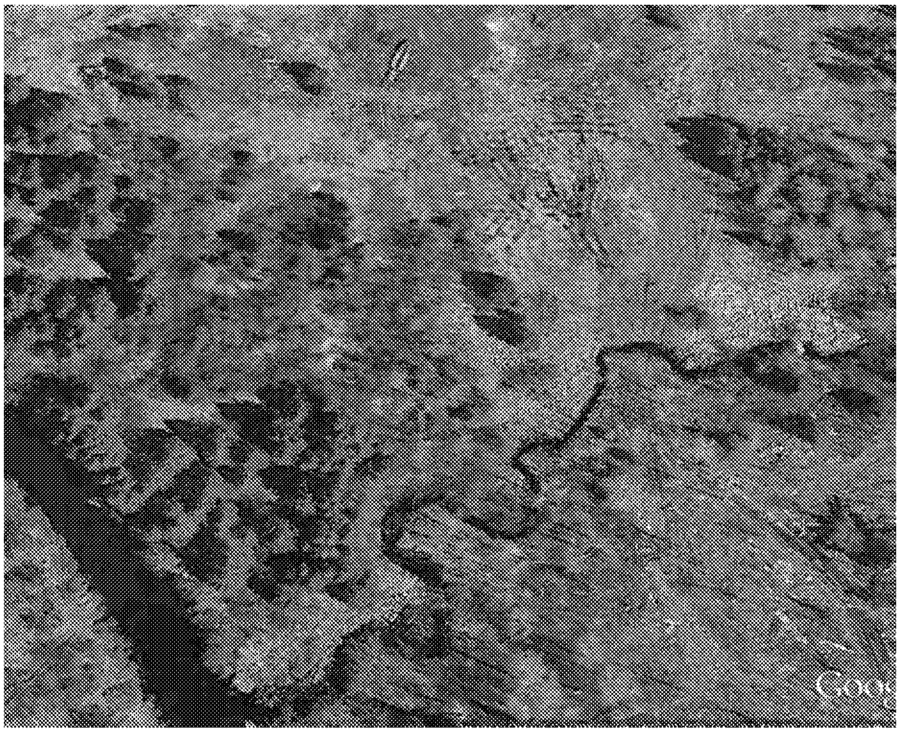
Macroinvertebrate community DO Index values in Water Hen Creek are generally lower than comparable reference streams in the SLRW (figure BLANK). The DO Index scores at station 09LS92, located near the mouth of Water Hen River, were below all class 4 sites scoring above the upper confidence limit and well below the 25th percentile scores for class 4 stations scoring above the impairment threshold (figure BLANK). The exception is station 10EM121, where the macroinvertebrate community DO index score is comparable to the majority of high-quality class 4 macroinvertebrate stations. DO data at this monitoring station are limited to a single measurement taken at the time of sampling in August 2010 (8.33 mg/L).

Another piece of evidence in support of low dissolved oxygen as a stressor in this watershed is the lack of EPT taxa richness and low overall EPT abundance observed in Water Hen Creek. The percent of individuals belonging to EPT taxa ranged from a minimum of 6.3% (09LS092, Sept '11) to a maximum of 13.5% (10EM121, Aug '10), with an average value of 8.3% among the four sampling visits to the three monitoring stations. In comparison, the average EPT % at class 4 stations that scored above the impairment threshold is 27.0% (n=45, 25th percentile =13.5%, min=2.2%, max=69.3%). Low dissolved oxygen concentrations are likely one of several factors limiting EPT richness and abundance in Water Hen Creek.


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% of total macroinvertebrate assemblage
09LS094 (Aug '09)
10EM121 (Aug '10)
09LS092 (Aug '09)
09LS092 (Sep '11)
Tolerance to Low Dissolved Oxygen
No Tolerance Value
Highly Tolerant
Moderately Tolerant
Neutral
Moderately Intolerant
Highly Intolerant


Intolerant
tolerant
Macroinvertebrate Community DO Index Scores*
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
n=19
n=39
n=50
SLR Class 4 AUCL
SLR Class 4 AT
SLR AUCL
Boxplots show quartiled values for x-axis headings
Water Hen Ck. Biological Stations
09LS092
09LS092
10EM121
Key: SLR = St. Louis River Watershed AUCL = Above Upper Confidence Limit of IBI AT = Above IBI Threshold



pH / Low Ionic Strength

Habitat

Paleface Creek

Dissolved Oxygen

<u>Sources and Pathways Contributing to Low Dissolved Oxygen</u>

Paleface Creek drains a watershed with flat topography and an abundance of shallow lakes and wetlands. Over 50% of the watershed area is comprised of wetlands (45%) and open water (7%). The lakes in this watershed are generally shallow and tannin stained. Dinham Lake, which outlets to a tributary stream flowing north into Paleface Creek, is impaired for excess nutrients and failing to meet MPCA's lake eutrophication criteria. Less than 2% of the watershed area is developed and most of this development is located around Dinham and Berg Lake.

Total phosphorous (TP) concentrations in Paleface Creek are slightly elevated, with several samples exceeding the draft river nutrient TP criteria of 0.055 mg/L. TP data for Paleface Creek are limited, and many of the results are from high flow periods (snowmelt, rain events). A maximum TP concentration of 0.071 mg/L was observed in July of 2009 (n=7, min=0.019 mg/L, mean=0.038 mg/L). Despite TP concentrations above the river nutrient criteria standards, primary productivity in Paleface Creek appears to be limited based on very low diurnal DO flux and sparse to moderate density of aquatic macrophytes in the stream channel. Paleface Creek is extremely tannin stained and the lower water transparency also serves a limiting factor for primary productivity.

The low dissolved oxygen concentrations observed in Paleface Creek are likely driven by interactions between the stream and its adjacent wetlands. The entire length of Paleface Creek is bordered an extensive riparian corridor consisting of woody and emergent herbaceous wetlands (figure BLANK). Nearly all of the adjacent wetlands can be categorized as Organic Flat HGM type wetlands.

Biological Response to Low Dissolved Oxygen

Fish

The fish community observed at Paleface Creek station 09LS049 is dominated by species that are very tolerant of low dissolved oxygen conditions. Central mudminnow were the most abundant species observed and accounted for 63% and 83% of the fish community during the two sampling visits. Other species that were present in very small numbers include black bullhead, white sucker, tadpole madtom, pumpkinseed sunfish, and northern pike. Aside from white sucker and tadpole madtom, every species of fish observed in Paleface Creek can be considered highly tolerant of low dissolved oxygen conditions. Based on data from the two fish sampling visits, approximately 87 to 97 percent of the fish observed in Paleface Creek are from species known to be highly tolerant of low DO.

Station 09LS049 scored poorly in the fish community DO index, which is another tool used to assess the overall tolerance level of the fish community to low dissolved oxygen. Figure BLANK shows a comparison of the DO index score at 09LS049 to scores from reference streams of the same Fish IBI class in the SLRW. The DO Index scores at 09LS049 (5.8 and 5.6) fall near the bottom of the lower quartile values observed at comparable reference stations. It is clear from this comparison that the Paleface Creek fish community is more tolerant of low DO conditions than high quality streams of the same fish IBI class.

In addition, Paleface Creek scored poorly in several other fish IBI metrics that are often linked to low dissolved oxygen as a stressor. Station 09LS049 received poor scores for metrics related to overall fish abundance, a lack of headwaters minnow species, and a lack of sensitive fish species. Although these metrics can be responsive to a variety of stressors, these results are further evidence in support of low dissolved oxygen as a stressor in Paleface Creek.

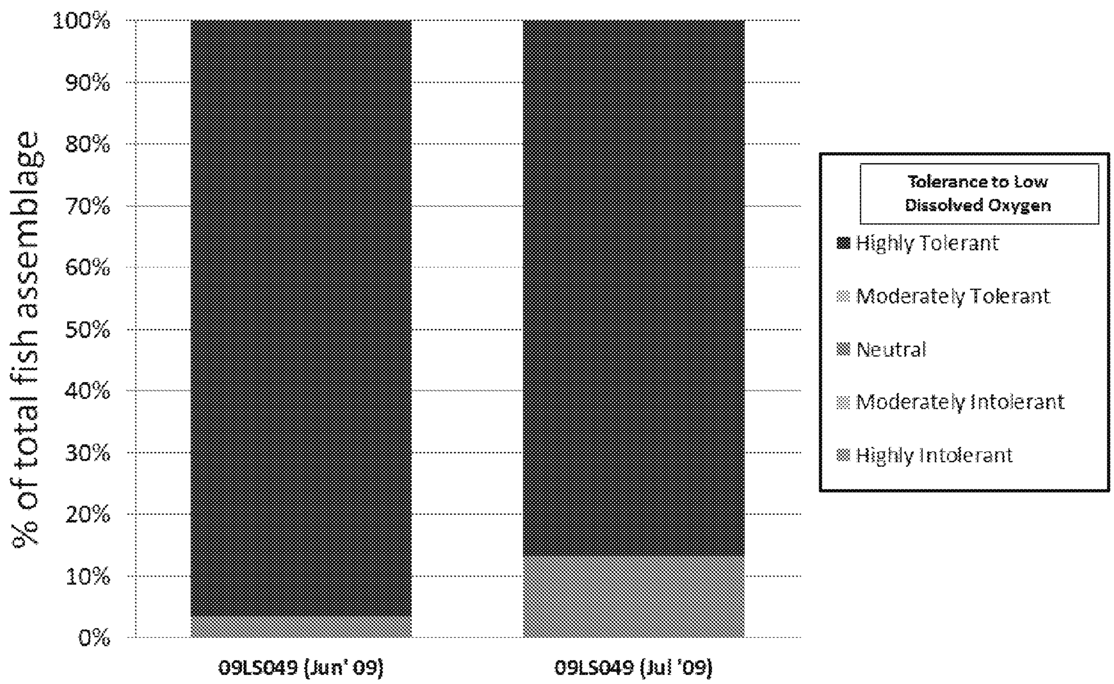
Macroinvertebrates

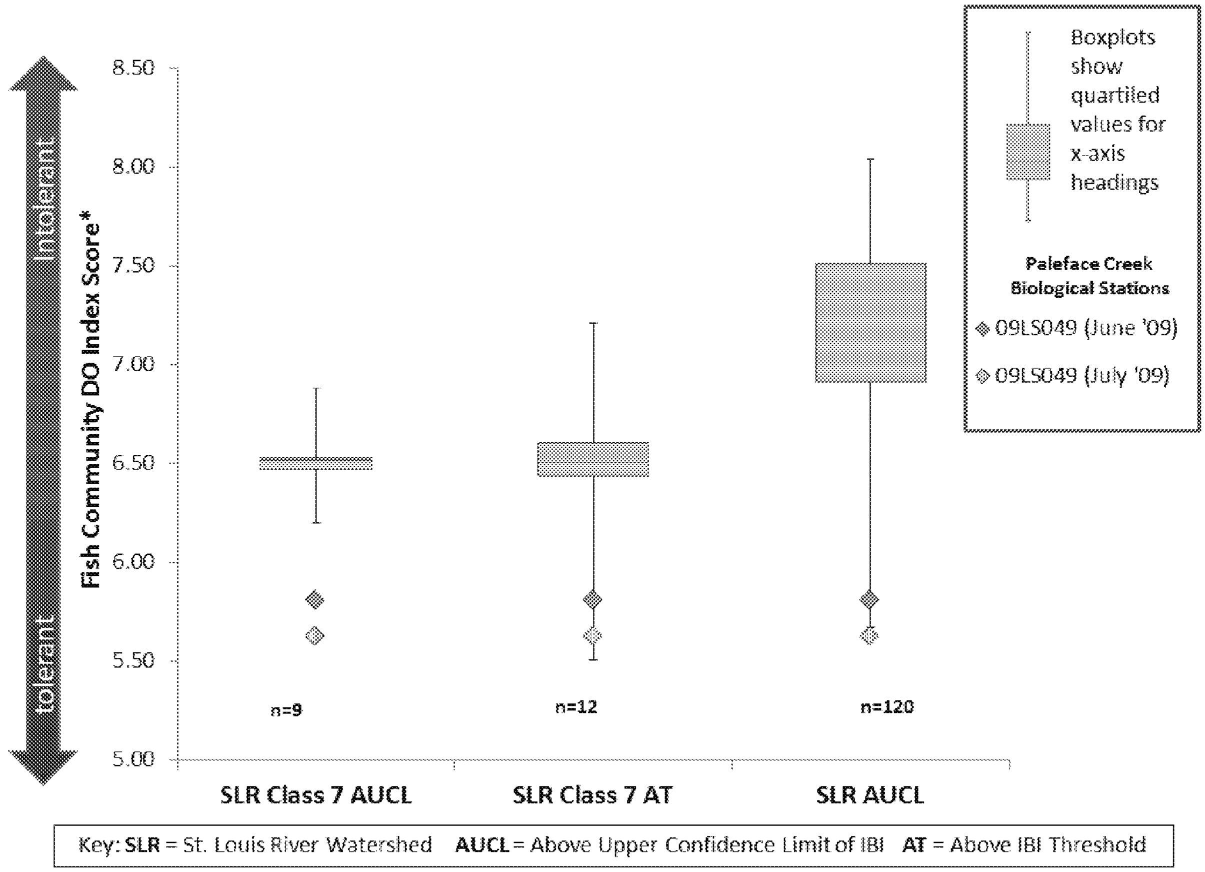
Nearly 80% of the macroinvertebrates sampled at station 09LS049 on Paleface Creek belong to taxa that are moderately to highly tolerant of low dissolved oxygen (figure BLANK). Other than aquatic worms (Oligochaeta), amphipod crustaceans (Hyallela) were the most abundant macroinvertebrate at this station, accounting for nearly 40% of the total organisms sampled. Members of this genus are considered highly tolerant of low dissolved oxygen conditions and elevated nutrient concentrations. Hyalella individuals feed primarily on decaying organic matter, which appears to be abundant in Paleface Creek due to the low gradient, wetland setting the creek passes through. Other macroinvertebrate taxa that were abundant at this monitoring station included several genera of non-biting midges from the family Chironomidae; *Cricotopus*, *Ablabesmyia*, *Tanytarsus*. These taxa can be considered neutral to moderately tolerant of low dissolved oxygen levels.

The macroinvertebrate community DO Index value at station 09LS049 is lower than the scores observed at comparable reference sites (BLANK). The low DO index score driven by two factors at this station; (1) it supported only one taxa that is intolerant of low dissolved oxygen concentrations ( ), and (2) 50% of the total macroinvertebrate community was comprised of individuals belonging to taxa that are tolerant of low dissolved oxygen conditions.

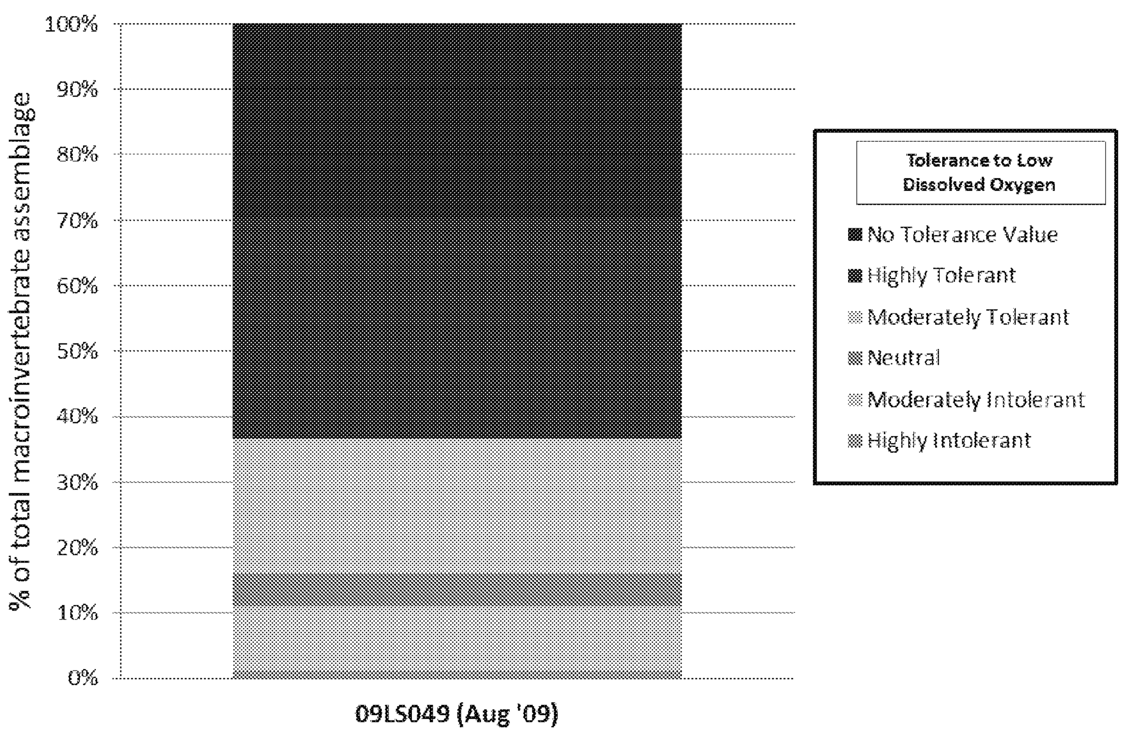
Summary

Biological data offer firm support of low dissolved oxygen as a stressor in the impaired reach of Paleface Creek. The fish and macroinvertebrate communities are both symptomatic of a DO-limited environment, with low taxa richness and abundance measures, as well as communities that are dominated by taxa that are tolerant of low dissolved oxygen concentrations.

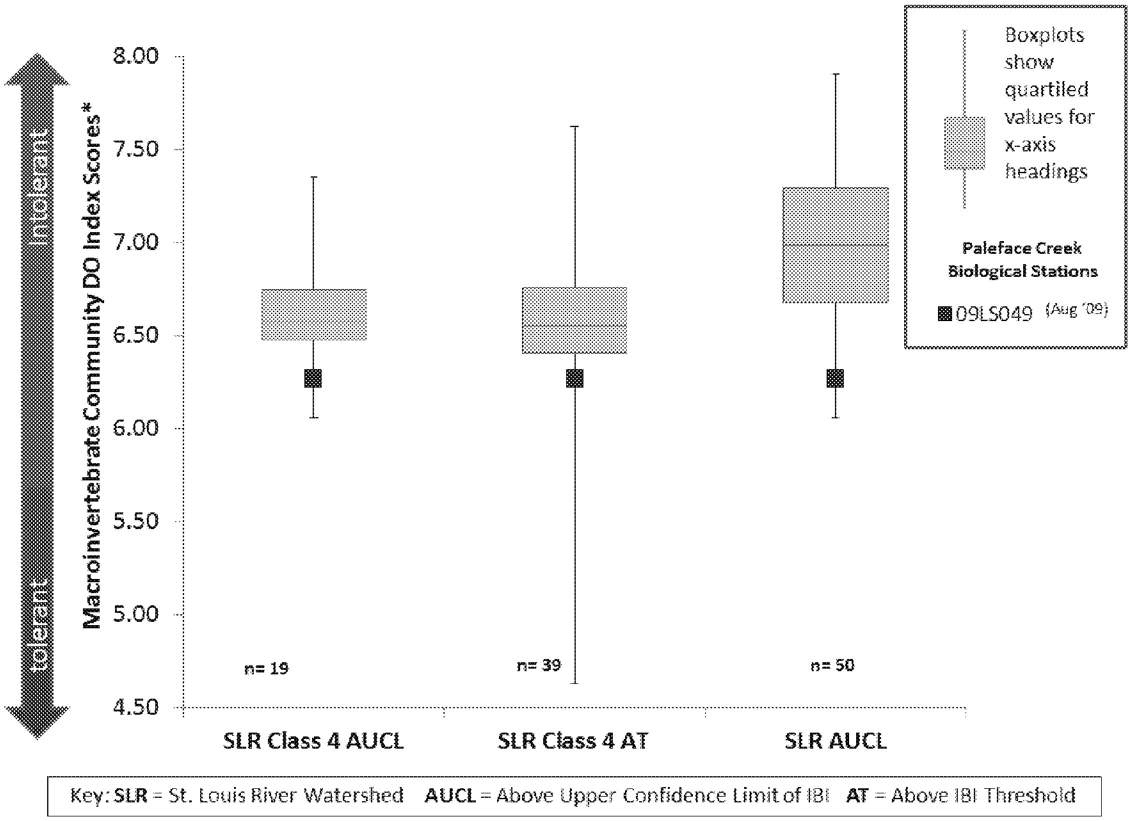




Intolerant
tolerant
Fish Community DO Index Score*
8.50
8.00
7.50
7.00
6.50
6.00
5.50
5.00
n=9
n=12
n=120
SLR Class 7 AUCL
SLR Class 7 AT
SLR AUCL
Boxplots show quartiled values for x-axis headings
Paleface Creek Biological Stations
09LS049 (June '09)
09LS049 (July '09)
Key: SLR = St. Louis River Watershed AUCL = Above Upper Confidence Limit of IBI AT = Above IBI Threshold



% of total macroinvertebrate assemblage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
09LS049 (Aug '09)
Tolerance to Low Dissolved Oxygen
No Tolerance Value
Highly Tolerant
Moderately Tolerant
Neutral
Moderately Intolerant
Highly Intolerant

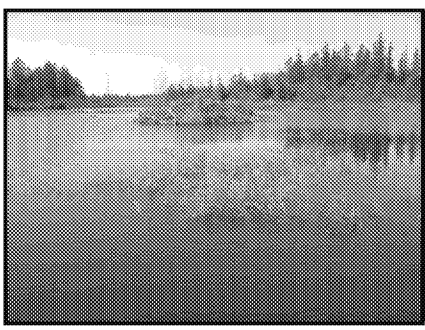


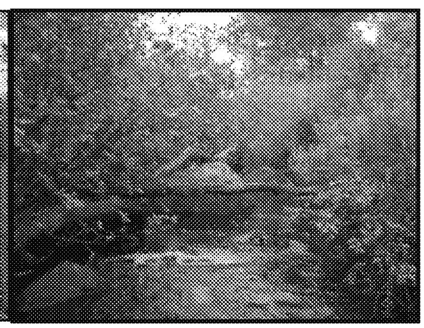
pH / Low Ionic Strength

Habitat

Laurentian Uplands – Partridge River Watershed Zone

Wyman Creek is the lone impaired stream in the Laurentian Uplands – Partridge Headwaters (LU-P) watershed zone. The headwaters of Wyman Creek originate from a series of abandoned mine pits which deliver water to the creek at a fairly constant rate all year round. The influence of these mine pits on the water quality, temperature, and physical habitat of this stream will be discussed later in this report. Historically, small populations of brook trout have been sampled in the lower reaches of Wyman Creek, which are steeper in gradient and dominated by cobble and small boulder substrate. The upper reach of Wyman Creek is a sinuous, low gradient channel meandering through bogs and wetlands. Riffle and run features are extremely limited in the upper ¾ of the stream and substrate is dominated by fines (sand/silt) throughout this reach. Beaver dams were observed throughout the length of the creek during a survey completed in August of 2010. Based on the historical presence of brook trout, Wyman Creek remains a designated trout stream, despite a lack of trout in the more recent monitoring efforts.





Wyman Creek supports several fish species that are commonly found in high-quality trout streams in Northeastern Minnesota, such as mottled sculpin, longnose dace, finescale dace, and pearl dace. However, repeat sampling results show robust populations of fish species that often take over marginal or degraded trout streams. Creek chub, black crappie, yellow perch, blacknose dace, and common shiner are examples of undesirable species that were commonly observed in Wyman Creek fish surveys. The presence of these species suggests that the stream is a marginal coldwater stream due to natural background conditions, or that is has been degraded due to anthropogenic stressors. The specific stressors impacting Wyman Creek will be discussed in this section.

Temperature

Temperature data was collected in 2009, 2012, and 2013 at five sites on Wyman Creek: 81LS008 upstream of CR 666, S007-268 upstream of Forest Road 117, S007-212 at the outfall of Pit #3, and S007-213 and S007-214 upstream and downstream of the Pit #3 outfall. Only data between June 1 and August31 were analyzed.

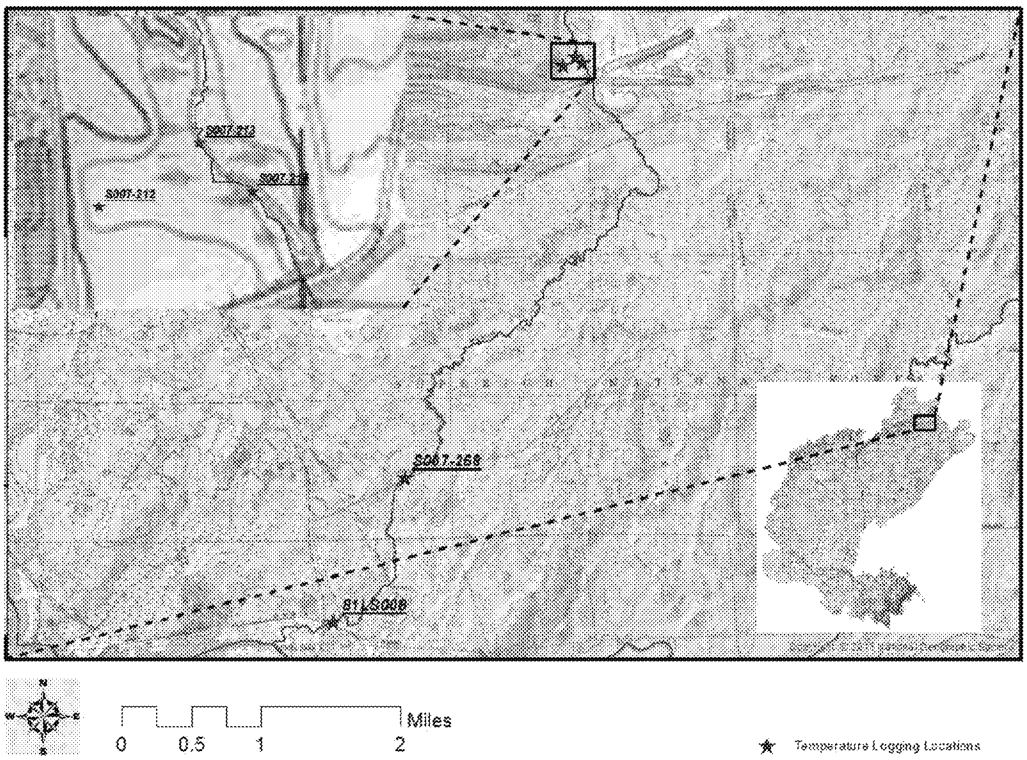


Figure X: HOBO logger locations on Wyman Creek

Figure X shows that, apart from early June, the average maximum daily temperature well exceeded the stress threshold of 68° F for the entire summer. During almost the whole month of July, the *average* stream temperature exceeded the stress threshold. The temperature profile of Wyman Creek is not representative of a healthy coldwater stream.

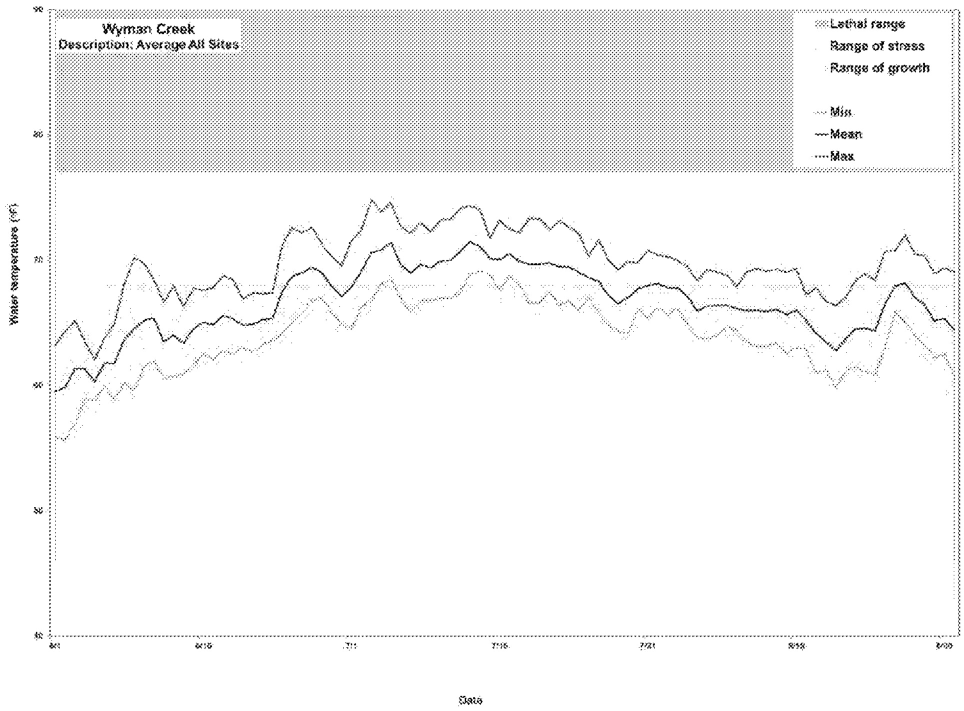


Figure X: Average daily minimum, mean, and maximum temperatures for all temperature loggers at all sites in Wyman Creek

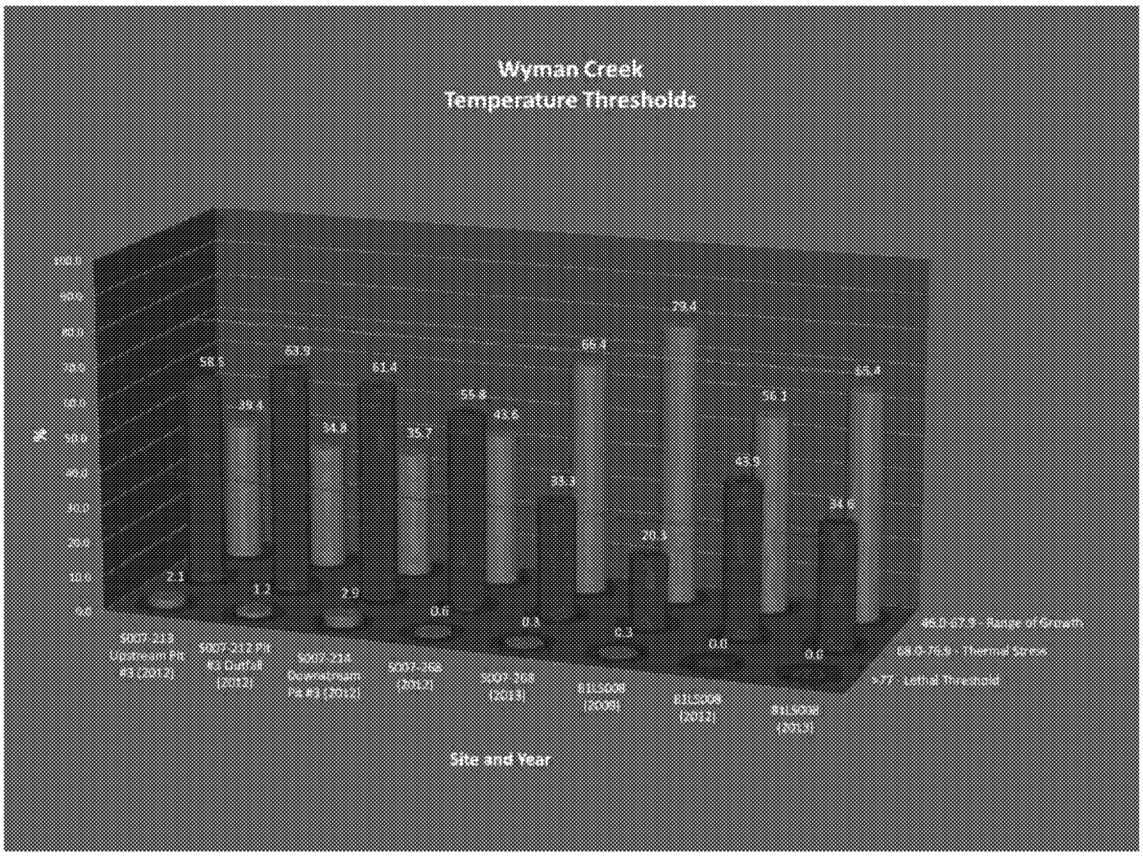
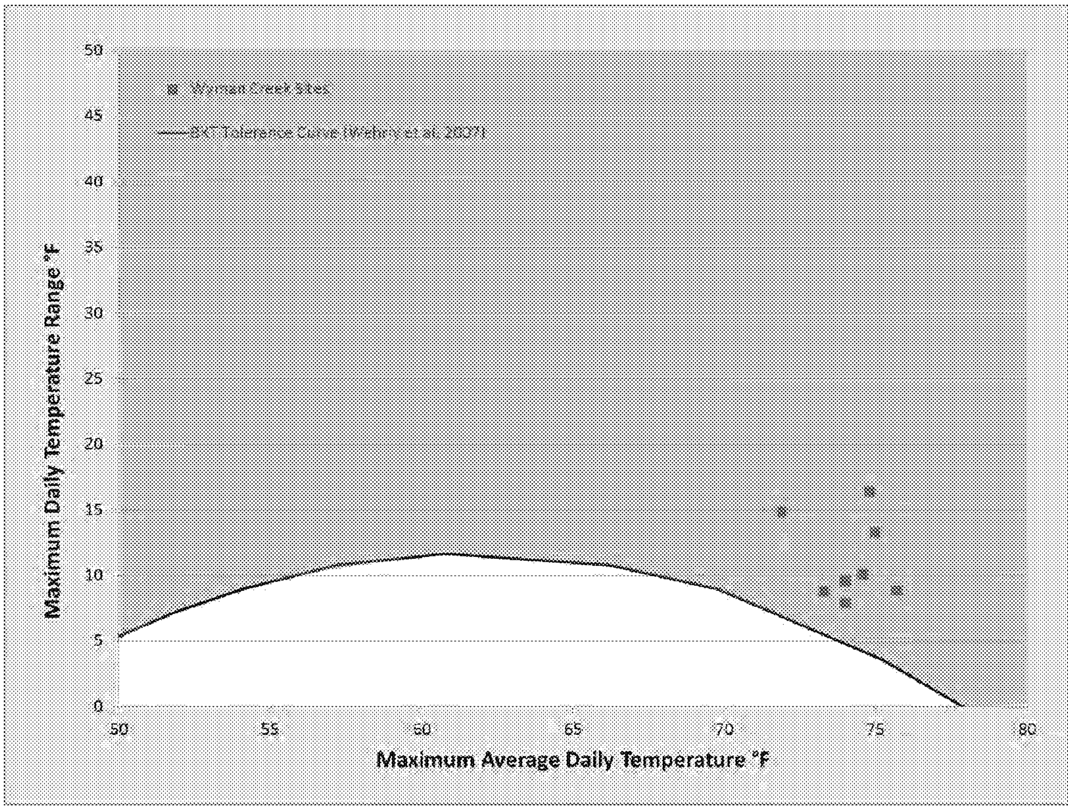


Figure X: Percentage of time spent in BKT growth, stress and lethal ranges

Figure X shows the site-specific breakdown of the temperature data, which was evaluated using at least 70% of the time in growth temperature (46.0-67.9° F) as the indicator of whether or not BKT should be present based on water temperature alone. It is evident that the water temperature in Wyman Creek is too warm for coldwater species. Every logger except one fell below 70% growth, and the one that exceeded 70% was deployed in 2009 – Minnesota's 7th coldest summer on record (www.noaanews.noaa.gov/stories2009/20090910_summerstats.html).

The Wyman Creek watershed contains two possible sources of temperature loading –mine pits and beaver dams. Both impede water flow and increase the surface area available for the stream to absorb solar energy. Beaver dams have the added effect of flooding and killing riparian forests so that even when the beaver dams breach, the shading that used to be provided by the canopy trees is gone. The silt, clay and other organic matter deposited behind beaver dams is also easily re-suspended by wildlife, darkening the water and aiding in heat absorption. Historic MNDNR surveys have recorded brook trout in this stream, but no trout were sampled in the most recent survey. Historic photos of the watershed indicate a large increase in beaver activity in the last ~25 years. Current beaver dam density is 3.4 dams/mile. In 1991 the density was 1.6 dams/mile (counted from Google Earth historic imagery). Additionally, Pit #5S at the headwaters of Wyman Creek was flooded in the 1990's and now outflows directly into the stream. These two fairly recent phenomena are likely contributing to higher stream temperatures and help explain why trout may no longer be present in the stream.

Figure X: An example of a large beaver dam and the turbid water typical throughout Wyman Creek.



Temperature data for all Wyman Creek sites was plotted using similar methodology to a trout temperature tolerance study in Wisconsin and Michigan (Kevin E. Wehrly , Lizhu Wang & Matthew Mitro (2007) Field-Based Estimates of Thermal Tolerance Limits for Trout: Incorporating Exposure Time and Temperature Fluctuation, Transactions of the American Fisheries Society, 136:2, 365-374, DOI: 10.1577/T06-163.1). Every site falls outside the tolerance limit for BKT. This analysis suggests that both maximum temperature *and* temperature fluctuation are limiting coldwater species, especially brook trout, in Wyman Creek. High temperature fluctuation is most likely due to the high sensitivity of the stream to ambient air temperatures. This situation is exacerbated by the high number of beaver- and man-made impoundments in the watershed.

Visit Number	Waterbody Name	Field Number	Fish Class	Fish IBI	Coldwater Taxa Present	Coldwater Intolerant %	Coldwater Sensitive Taxa %
20091142	Wyman Creek	81LS008	11	33	1	3.13	27.27
20121020	Wyman Creek	81LS008	11	46	1	0.00	22.22
				Average	1	1.56	24.75

Unimpaired Sites	20091057	Dutch Slough	09LS014	11	49	1	9.09	40.00
	20091147	Hay Creek	97LS108	11	71	2	51.49	42.86
	20091156	Keene Creek	95LS028	11	61	1	27.47	25.00
	20091146	Little Otter Creek	09LS116	11	51	2	2.33	30.00
	20091012	Midway River	09LS117	11	55	2	15.43	30.77
	20091013	Midway River	09LS118	11	61	3	15.71	35.71
	20091068	Midway River	09LS117	11	59	2	23.44	30.77
	20091037	Pine River	09LS013	11	50	2	5.42	22.73
	20091065	Pine River	09LS013	11	53	2	1.78	31.25
	19970052	Trib. to Midway River	97LS039	11	63	2	2.74	57.14
	20091153	Trib. to Midway River	97LS112	11	52	1	23.38	44.44
	19970087	White Pine River	97LS083	11	63	2	15.55	38.46
	20091148	White Pine River	09LS115	11	55	1	5.88	28.57
					Average	1.8	15.36	35.21

Table X: Coldwater metrics of Wyman Creek and unimpaired coldwater streams in the St. Louis River watershed

An analysis of coldwater biological metrics reaffirms temperature as a stressor compared with unimpaired coldwater sites in the St. Louis River watershed. From two reportable visits to Wyman biosite 81LS008, the average coldwater taxa present was 1.0, the average percent of coldwater intolerant individuals was 1.56%, and the average coldwater sensitive taxa percent was 24.75% (Table X). In contrast, the numbers for the unimpaired coldwater biosites are 1.8, 15.36% and 35.21%, respectively.

Restoration/Protection Strategies to Reduce Water Temperatures

4. Reduce temperature loading from impoundments
   a. Instead of draining the warm top water from abandoned mine pits, pumps could be installed to drain colder water from deeper in the water column.
   b. Beaver and beaver dam removal from the lower gradient reaches of the stream would have positive results in terms of water temperature, as well as spawning habitat, dissolved oxygen, connectivity, and decreased populations of non-trout fish that compete with brook trout for food.

Dissolved Oxygen

Available Dissolved Oxygen Data

Instantaneous dissolved oxygen (DO) data were collected at four stations along Wyman Creek. Two additional DO readings were collected through the ice in the winter of 2014. Two of these stations (S007-213 & S007-214) are located in the headwaters of the creek in an area of the watershed that is dominated by wetlands and mining land-uses. The other two stations are located in the lower reaches of Wyman Creek and are paired with the biological monitoring stations. Monitoring was conducted during the open water season 2009, 2012, and 2013. The DO concentrations observed at these four stations are displayed in figure BLANK.

DO concentrations in Wyman Creek fell below the class 2A (coldwater trout stream) standard of 7 mg/L at all monitoring stations during the months of June through September. Very low DO concentrations (sub 3 mg/L) were observed in the headwaters of Wyman Creek at station S007-213, but approximately 500 ft downstream, DO concentrations increased to around 5 mg/L due to a tributary stream entering the creek from an abandoned mine pit. This observation suggests that the specific mine-pit tributary mentioned above is not contributing to the sub-optimal DO conditions observed downstream. On the contrary, it may be improving the dissolved oxygen regime of Wyman Creek, at least locally. Other tributaries from mine pits and mining areas enter further upstream, but the effect of these tributaries on the mainstem of Wyman Creek is not known.

DO concentrations at the two biological monitoring stations failed to meet the water quality standard (7 mg/L) for supporting coldwater aquatic life. July and August DO levels at these stations were generally around 4 or 5 mg/L, which is adequate for supporting many warmwater species, but inadequate for supporting sensitive coldwater species such as brook trout. Early spring and late winter DO concentrations were adequate at these sites, so the period of DO-stress is limited to mid-summer and early fall periods.

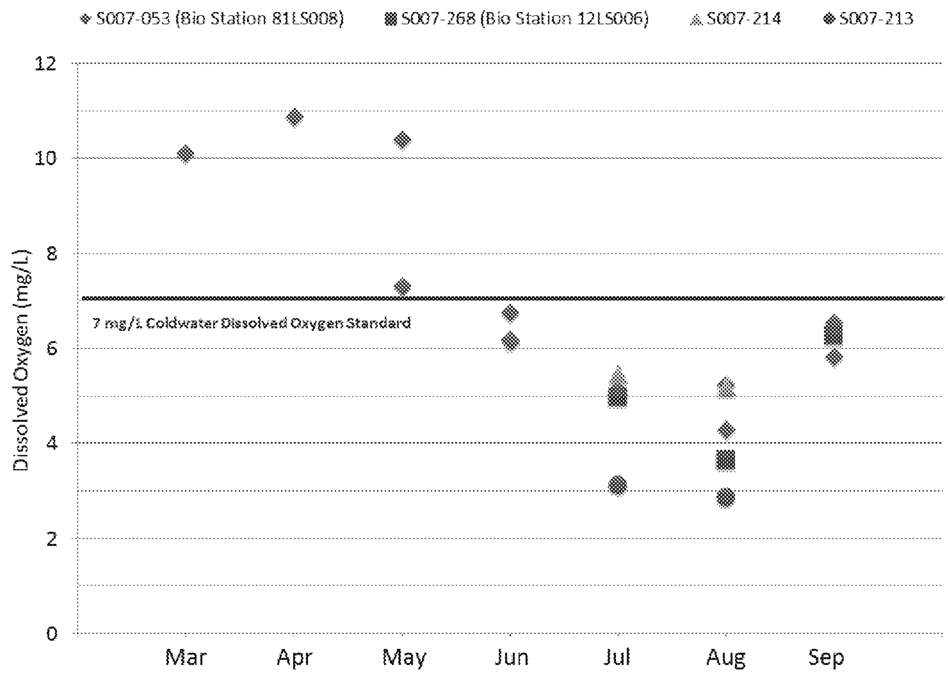
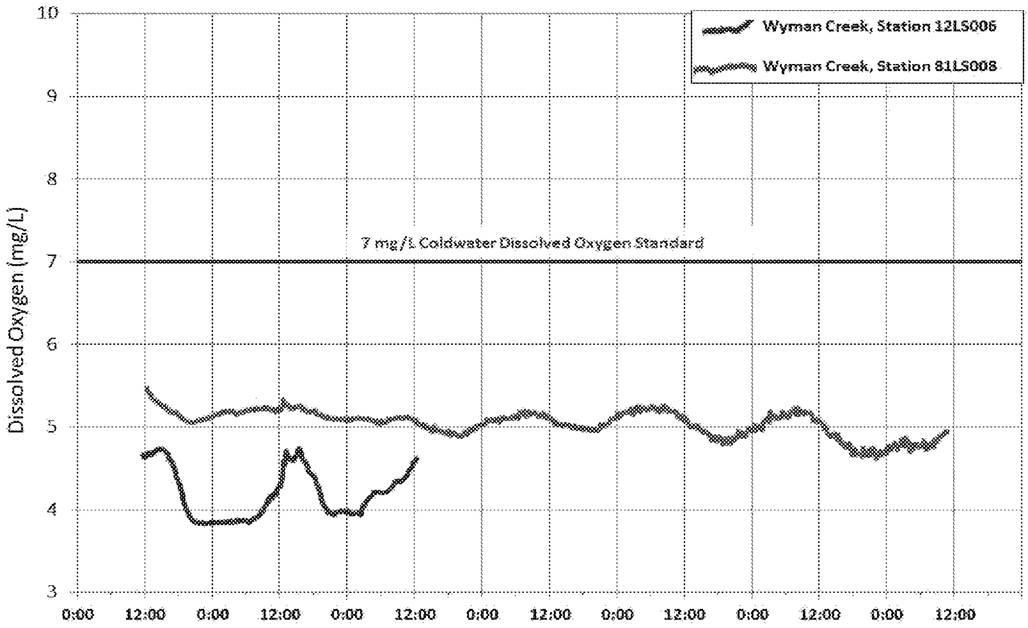


Figure BLANK:

Continuous dissolved oxygen data were collected at two biological monitoring stations on Wyman Creek in the summers of 2012 and 2013. Both of these DO profiles, shown in figures BLANK in BLANK, were conducted in late August at or near baseflow conditions. Dissolved oxygen data were collected at 15-minute intervals for a period of 4-6 days. An equipment malfunction limited the 2012 profile at station 12LS006 to just over 24 hours.

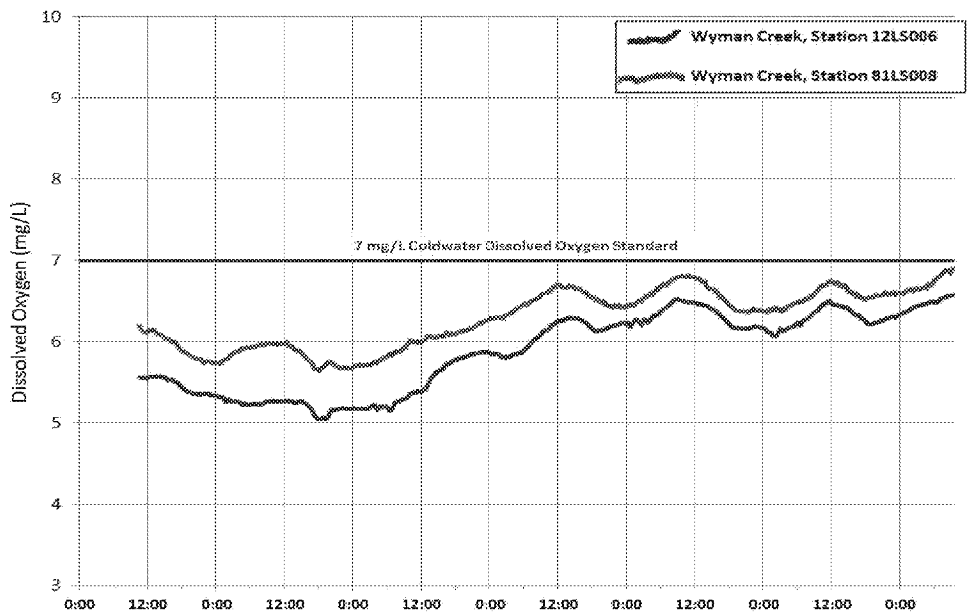
Dissolved oxygen concentrations remained below the 7 mg/L dissolved oxygen standard at both locations for the entire duration of the monitoring periods in both 2012 and 2013 (figure BLANK and BLANK). In both profiles, DO concentrations were lower at the upstream monitoring station (12LS006), where DO levels fell below the warmwater standard of 5 mg/L on occasion. Cooler water temperatures near the end of the 2013 survey caused a steady increase in DO concentrations at both monitoring sites. Daily maximum water temperature dropped from 22.8 C down to 18.6 C during this time, which led to an increase in the availability of DO within the water column.

Diurnal DO flux is very minimal in Wyman Creek based on the two continuous monitoring data sets. Maximum DO flux was below 1 mg/L at all monitoring stations during the 2012 and 2012 monitoring efforts. The low diurnal flux in DO concentrations is an indication that primary productivity is low within these two reaches of Wyman Creek, and that the lower DO concentrations observed may be due to factors other than stream eutrophication (i.e. beaver impoundments, lack of stream flow, wetlands)



Dates of Monitoring Period	# of Readings	DO Min (mg/L)	DO Max (mg/L)	Avg 24-hr Flux (mg/L)	Max 24-hr Flux (mg/)	% Readings below Trout Stream Threshold (7 mg/L)	Avg. Duration below (hours)	Max Duration below (hours)
8/24/2012 - 8/30/12	570	4.89	5.33	0.366	0.61	100%	142.5	142.5
8/24/2012 - 8/26/12	196	3.83	4.73	0.89	0.89	100%	49	49

Figure BLANK:



Dates of Monitoring Period	# of Readings	Min (mg/L)	Max (mg/L)	24-Hour Flux Data Average (mg/L)	Max (mg/L)	% Readings below Coldwater DO Threshold - (7 mg/L)
8/30/2013 - 9/5/13	583	5.64	6.7	0.45	0.58	100%
8/30/2013 - 9/5/13	582	5.05	6.58	0.46	0.72	100%

Figure BLANK:

Sources and Pathways Contributing to Low Dissolved Oxygen

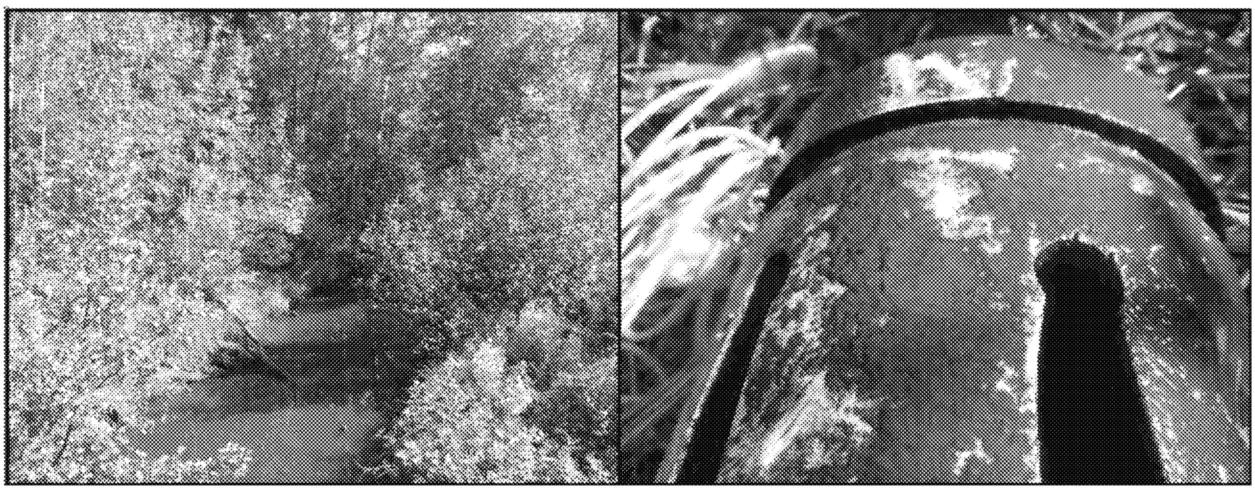
Total phosphorous (TP) concentrations observed in Wyman Creek were all below the stream nutrient criteria northern MN target of 0.055 mg/L (n=11, avg.=0.024 mg/L, max=0.035 mg/L). Very little periphyton algae or aquatic macrophytes were observed in the channel. These observations, along with the low diurnal DO flux observed during continuous monitoring, provide evidence against stream eutrophication as a cause of low DO concentrations.

Iron Precipitate ("Iron Floc")

Iron precipitation is predominantly a pH dependent oxidation of primarily soluble ferrous iron (Fe^{2+}) to particulate ferric iron (Fe^{3+}) (Broshears et al. 1996). In streams with a pH below 3, iron will typically remain in a soluble form (Harding and Boothroyd, 2004). However, when conditions occur that trigger a rise in pH (i.e. precipitation events, confluence with tributary stream), a precipitate (Fe^{3+}) often forms and is deposited on stream substrates. In most cases, this process involves one or several types of bacteria. At least 18 different types of bacteria are classified as "iron bacteria," which are long, thread-like organisms that "feed" on iron and secrete slime as a bi-product. Unlike most bacteria, which feed on organic matter, iron bacteria fulfill their energy requirements by oxidizing ferrous iron (Fe^{2+}) into ferric iron (Fe^{3+}). Ferric iron (Fe^{3+}) is insoluble and precipitates out of the water as a rust colored deposit. This process can occur naturally, when iron-rich groundwater is exposed to the atmosphere, but it can also be the result of land-uses which introduce

Iron precipitates similar to those observed in Wyman Creek have the ability to restrict the distribution, abundance, and diversity of fishes (Dahl, 1963; Amelung, 1982) in stream.

Smith et. al (1989) found observed an increase in Fe^{2+} concentrations following water transport through a beaver dam.



Beaver Dams

Wyman Creek and its tributary streams are heavily impounded by beaver dams. A total of 42 beaver dams were identified along the 10-mile length of Wyman Creek using recent aerial photos, which equates to about 1 impoundment for every 1,200 feet of stream (figure BLANK). There is considerable debate on whether or not beaver dams are beneficial or detrimental to stream habitat, but there is no debating that the Wyman Creek stream corridor is heavily influenced by beaver activity. These impoundments may have direct impacts on channel morphology, fish passage, and streamflow throughout the length of the creek. Indirectly, the beaver dams have the potential to increase water temperatures, as well as decreasing dissolved oxygen concentrations due to the warmer water temperatures and lower streamflow velocities. No data were collected in this study that allow for direct comparisons between reaches influenced by beaver, and those left relatively or completely unaltered. As a result, the connection between beaver dams and low dissolved oxygen in Wyman Creek are unknown, and need further evaluation during the TMDL development and implementation phase of the impaired waters process.

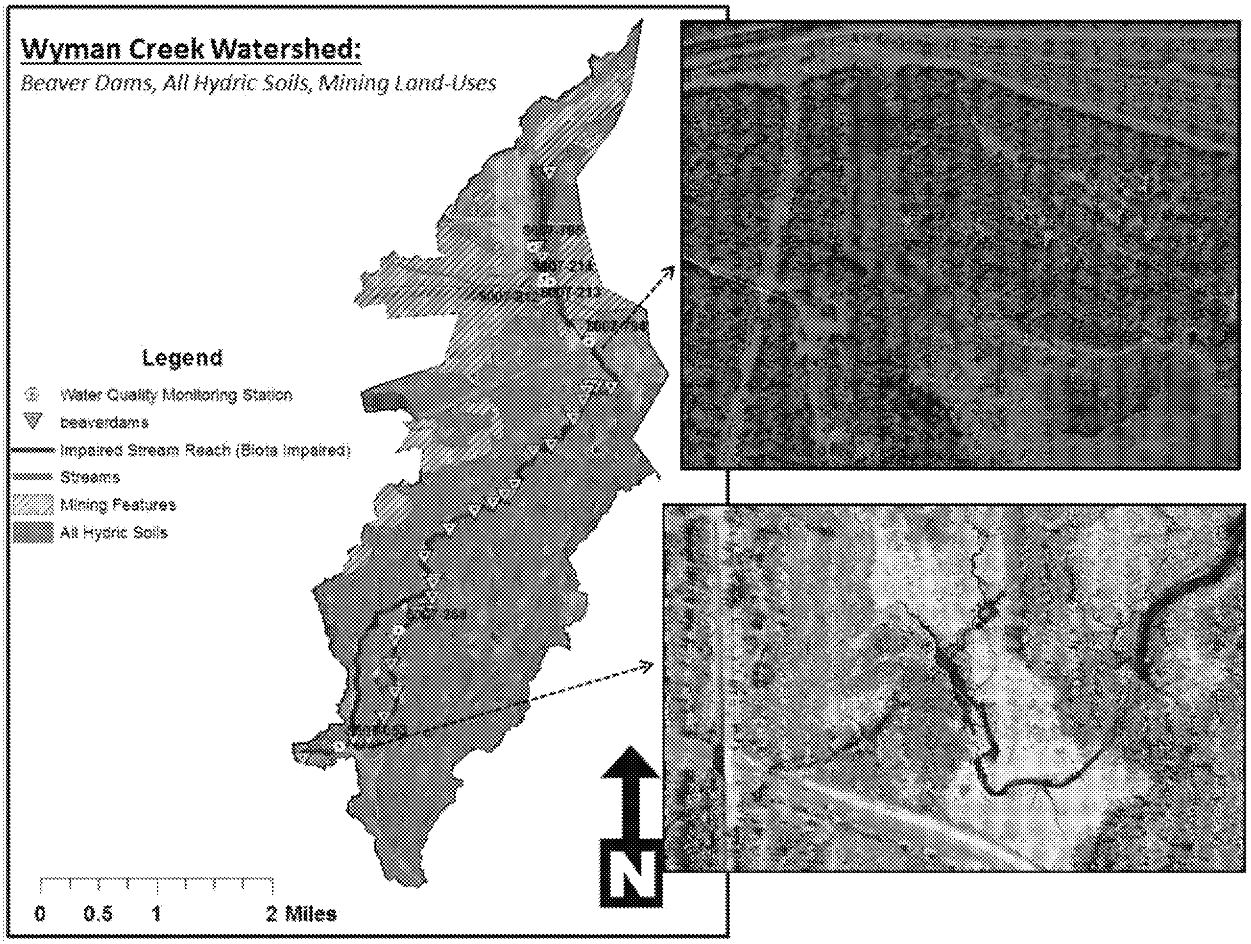
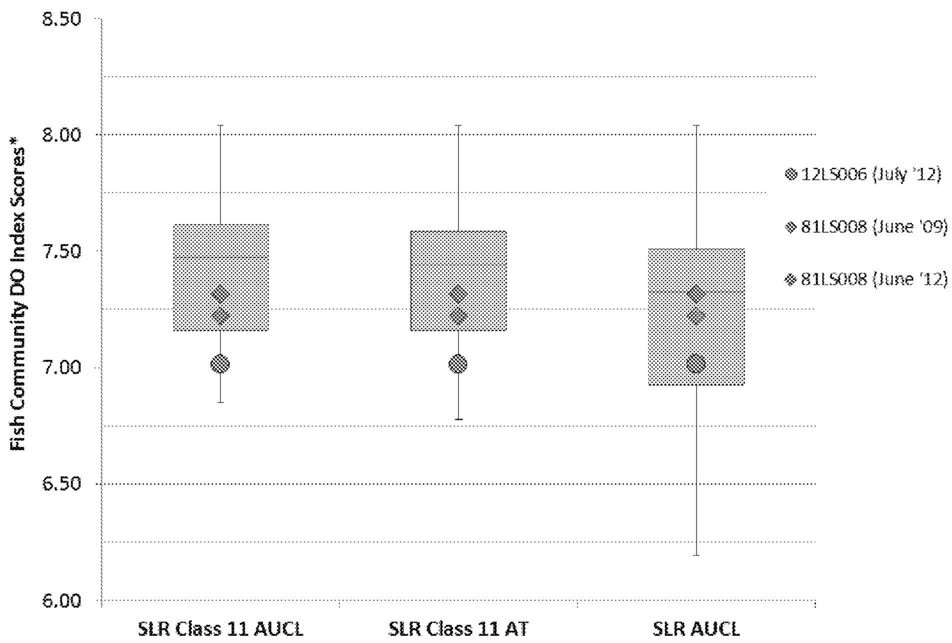


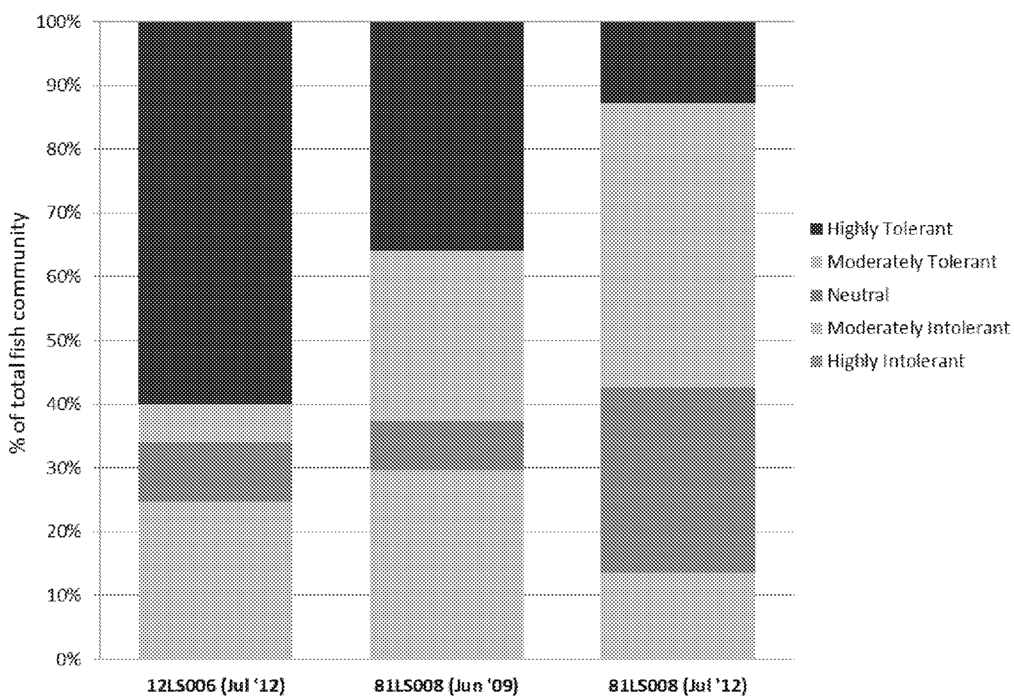
Figure BLANK: Map of beaver dam locations, mining-related land-use features, and all hydric soil types within the Wyman Creek watershed.

Biological Response to Low Dissolved Oxygen

The fish community of Wyman Creek includes a mix of coldwater and warmwater species with a range of tolerance to low dissolved oxygen concentrations. An average of 18% of the fish observed at 81LS008 over the two monitoring visits were coldwater species that are moderately intolerant of low dissolved oxygen. Mottled sculpin were present at the downstream monitoring station (81LS008) during both sampling events, and were fairly abundant relative to other species present. Longnose dace, another fish species that is commonly found in high-quality coldwater streams in northeastern Minnesota, were also present at 81LS008 during one sampling visit in limited numbers. The monitoring station located further upstream (12LS006) did not support any coldwater species during the time of sampling. Instead, this reach was pearl dace, blacknose dace, and creek chub. Pearl dace, a coolwater wetland species with a fairly high tolerance to low dissolved oxygen concentrations, accounted for 56% of the total sample at this station. Overall, species that are very tolerant of low dissolved oxygen (central mudminnow, brook stickleback) were not a dominant presence in the fish community.

The DO index values for the fish community of Wyman Creek are slightly lower than most of the values recorded at high quality coldwater streams in the SLRW (figure BLANK). The DO index for the fish community at 81LS008 falls between the 25th percentile and the median value for comparable reference sites. These results support the claim that this reach of Wyman Creek is not dominated by species that are tolerant of low dissolved oxygen, yet it does not provide ideal conditions for DO sensitive coldwater species like brook trout. DO index scores are lower at station 12LS006 due to the large population of pearl dace at this station, as well as the presence of northern redbelly and finescale dace. These fish species are commonly found in wetland dominated landscapes, which tend to have more marginal DO conditions for supporting a diverse fish assemblage.





TSS / Turbidity

Iron / Iron Floc

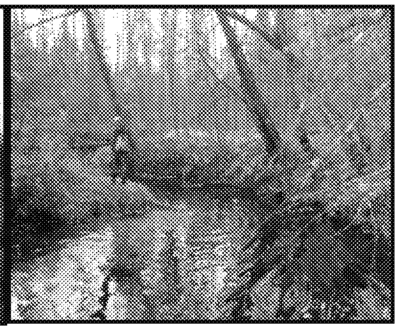
Sulfate

Beaver Dams

Nashwauk Uplands – Embarrass River Watershed Zone

Impaired streams of this watershed zone include Spring Mine Creek, Ely Creek, and the headwaters reach of the Embarrass River. These impaired segments of these streams share similar natural background qualities in that they are relatively low in gradient, moderately sinuous, and have broad floodplains with wetland qualities. Beaver dams are common features in all three of these streams, and these impoundments appear to have a significant effect on channel pattern, in-stream habitat, and water surface slope. Physical habitat conditions in these streams are somewhat limited due to the lack of riffle-run features and an abundance of fine substrates. Mining activity in this watershed zone introduces the potential for point-source pollution as a stressor, particularly in the case of Spring Mine Creek, which originates from a mine pit high atop Giants Ridge.





Overall fish counts were low in all three of the impaired streams in this watershed zone, and the species present were generally not sensitive or intolerant of disturbance. Species tolerant of low dissolved oxygen (central mudminnow, brook stickleback) were present in high numbers relative to other fish species at impaired sites. Aside from a very small population of pearl dace observed in Spring Mine Creek, headwaters minnow species and darter species were absent from the impaired reaches.

The habitat conditions available in these low-gradient, wetland dominated watersheds may be naturally limiting in terms of supporting a diverse fish assemblage. Bear Creek, a second-order tributary of the Embarrass River has been used as a reference stream in previous studies involving biological integrity in this region of the SLRW. There is very little development and no mining land-use in the Bear Creek watershed, but many of the natural limitations (low gradient, wetland riparian corridor, lack of coarse substrate) are shared with the Embarrass River and Spring Mine Creek. Despite its relatively intact watershed, Bear Creek scored only three points higher than the impairment threshold and is comparable to the impaired streams in terms of fish abundance and species distribution. The impaired streams in this watershed are certainly impacted by anthropogenic activity, but further analysis of available reference conditions to base restoration efforts on is recommended. The relative contributions of natural and anthropogenic stressors will be further discussed for these streams in the candidate causes for impairment section.

Spring Mine Creek

Spring Mine Creek is the only stream in this watershed zone that is listed as impaired for macroinvertebrate bioassessments. The M-IBI results from this stream were narrowly below the impairment criteria and do not suggest severe impairment. However, ancillary information considered in the assessment process (elevated specific conductivity readings; invertebrate samples dominated by Gammarus and Corixidae) resulted in an impairment listing. Symptoms of impairment observed in Spring Mine Creek include a very low relative percentage of non-hydropsychid caddisfly taxa (1.6%) and imbalance in the distribution of taxa present. Over 76% of the individuals counted were from the five most abundant taxa in the sample. Bear Creek, which has been discussed as a potential reference stream for this watershed zone (Source), shows more balance among taxa present, supports more intolerant taxa, and better representation from the order trichoptera (figure BLANK).

	Bear Creek		Spring Mine Creek	
M-IBI Metric	Metric Value	Metric Score	Metric Value	Metric Score
Richness of Intolerant Taxa*	3	***10.0***	1	***5.0***
% Trichoptera Taxa	18.9%	***10.0***	5.7%	***3.5***
% Trichoptera Taxa ***(excluding hydrophyschidae)***	5.8%	***7.8***	1.6%	***3.8***
POET Taxa Richness**	12	***7.1***	7	***3.6***
% Dominant Five Taxa***	65.2%	***5.4***	76.7%	***3.0***

* Taxa richness of macroinvertebrates with tolerance values (TV) less than or equal to 2, using MN TV (Chirhart, source)

** Taxa richness of Plecoptera, Odonata, Ephemeroptera, & Trichoptera (baetid taxa treated as one taxon)

*** Relative abundance (%) of dominant five taxa in subsample (chironomid genera treated individually)

Dissolved Oxygen

With only one road crossing and a high percentage of the watershed in private ownership, access to Spring Mine Creek for monitoring purposes was extremely limited. As a result, instantaneous dissolved oxygen (DO) data were collected at only one monitoring station. A total of 13 instantaneous DO measurements were collected between the months of April and November, with only one reading falling below the 5 mg/L warmwater DO standard (2.61 mg/L; 8/29/2013) (Figure BLANK). The majority of mid-summer DO concentrations recorded in Spring Mine Creek are in the range of 5-8 mg/L, which is a suitable range for supporting healthy warmwater fish and macroinvertebrate communities.

Continuous monitoring data for dissolved oxygen and other parameters were collected in 2011, 2012, and 2013 at biological monitoring station 09LS101. All of the continuous monitoring data were collected during the months of July or August. DO concentrations dropped below the warmwater standard of 5 mg/L in two of the three continuous monitoring periods. During the August 2011 DO survey, a minimum DO concentration of 4.62 mg/L was observed, but DO levels only remained below 5 mg/L for a short duration of 3 hours. A slightly lower minimum DO concentration of 4.37 mg/L was recorded during the July 2013 continuous monitoring period, and the duration of sub-5 mg/L DO was longer, at 12.3 hours. All of the DO concentrations recorded during the July 2012 survey were above the 5 mg/L dissolved oxygen standard.

Average dissolved oxygen diurnal flux (DO flux) in Spring Mine Creek ranged from 1.44 mg/L to 5.43 mg/L over the three continuous monitoring periods. A maximum DO flux of 5.43 mg/L was recorded during the August 2011 data collection. This maximum value exceeds the Northern river nutrient stressor criteria for DO flux, which is set at 4.00 mg/L. Maximum DO flux recorded in the other two continuous monitoring periods were 1.82 mg/L (July 2012) and 3.20 mg/L (July 2013). Based on these results, DO flux in Spring Mine Creek is highly variable, and is high enough at times to present stressful conditions to sensitive aquatic life.

Minimum DO concentrations in Spring Mine Creek drop below 5 mg/L periodically, but are generally not extremely low (e.g. below 2-3 mg/L) and duration of sub-5 mg/L DO periods tend to be short-lived based on available data. DO flux is likely more of a candidate stressor than low minimum DO concentrations. Each of these candidate causes for impairment will be further evaluated in this section.

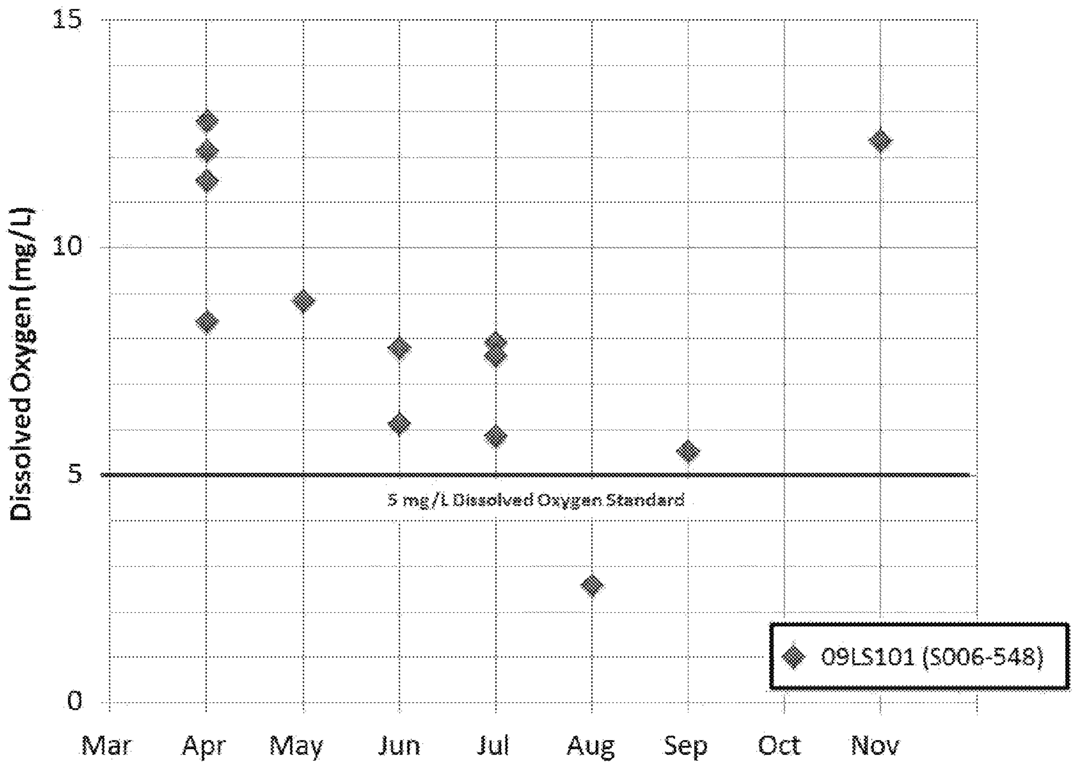
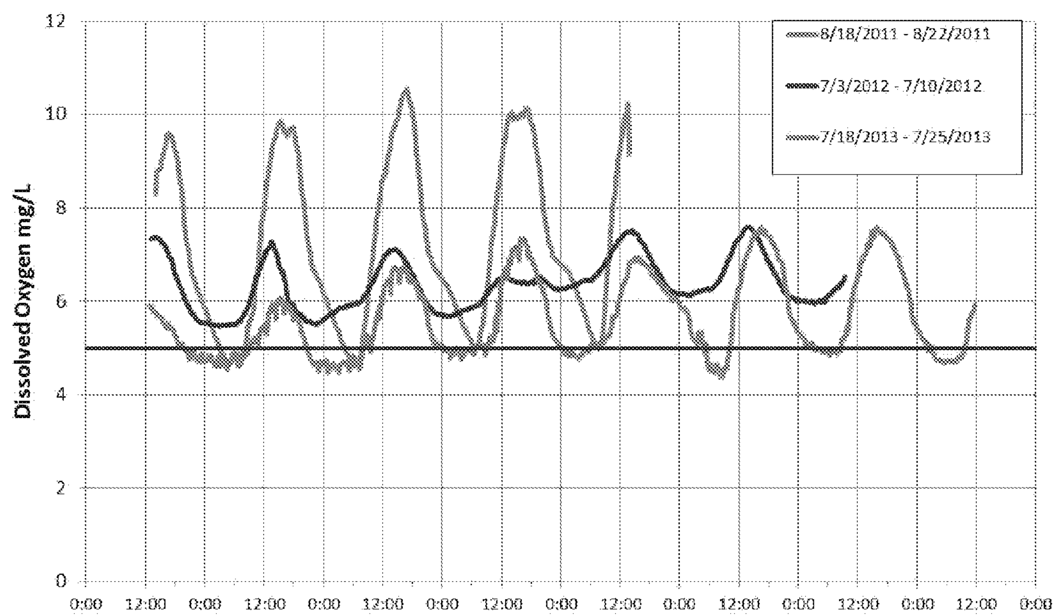


Figure BLANK:



	# of Readings	Min (mg/L)	Max (mg/L)	24-Hour Flux Data Average (mg/L)	24-Hour Flux Data Max (mg/L)	Warm Water Threshold - 5 mg/L % Readings below	Avg. Duration below (hrs)	Max Duration below (hrs)
8/18/2011 - 8/22/2011	384	4.62	10.55	5.43	5.92	9.4%	3	5.3
7/3/2012 - 7/10/2012	660	5.46	7.59	1.44	1.82	0.0%	0	0
7/18/2013 - 7/25/2013	669	4.37	7.57	2.42	3.20	32.6%	2.7	12.3

Figure BLANK

Sources and Pathways Contributing to Low Dissolved Oxygen

Total phosphorous (TP) concentrations in Spring Mine Creek ranged from 0.012 mg/L to 0.065 mg/L (n=7, avg. = 0.030 mg/L). Only 1 of the 7 results for TP exceeds the 0.055 mg/L nutrient criteria target for northern Minnesota streams and rivers. Many of TP data are from samples collected during snowmelt or rain events, and as a result, the nutrient concentrations may have been diluted. The one result exceeding the 0.055 mg/L TP target was observed during lower flow conditions in September of 2009. Based on the available data, it is difficult to determine whether or not TP concentrations are routuinely elevated during critical low flow periods.

Biological oxygen demand and chlorophyll-a data are not available for Spring Mine Creek at this time. Additional data collection efforts that include these variables would provide a clearer picture of the processes that are resulting in the rare low dissolved oxygen readings and the observations of elevated DO flux. Additional data will be collected in summer 2014 to evaluate these parameters.

The dissolved oxygen regime of Spring Mine Creek is likely influenced seasonally by the presence of submergent, emergent, and floating leaf aquatic vegetation. During site visits to station 09LS101, aquatic vegetation was generally present but somewhat sparse in the spring and early summer months. By August and September, a significant portion of the channel was typically covered by these vegetation types. As the amount of aquatic vegetation increases, DO flux generally increases as well due to photosynthesis and respiration process within the plant community. The elevated DO flux observed in Spring Mine Creek in August of 2011 may be linked to the increase in vegetation observed within the stream channel.

Figure BLANK: Photos of station 09LS101 looking upstream. Photo on the left was taken in June of 2009, and the photo on the right was taken in August 2009. Note the increase in floating leaf and emergent vegetation in the August 2009 photo.

Wetlands and hydric soil types are present in the Spring Mine Creek watershed, particularly in the riparian corridor along the middle to lower reaches of the creek. These features have the potential to release anoxic water, or water with lower dissolved oxygen content to the stream. Given that very few periods of extremely low dissolved oxygen were observed at station 09LS101, the linkage between wetlands and low dissolved oxygen does not appear to be as strong in this impaired sub-watershed. Instead, the wetland influence in Spring Mine Creek appears to be more related to elevated DO flux. Water clarity was generally much higher in Spring Mine Creek compared to other wetland-influenced streams of the SLRW, likely due to mine pits at its headwaters, which discharge very clear water to the creek and accounts for the majority of the flow in Spring Mine Creek during baseflow. The high water clarity and stagnant flows of Spring Mine Creek at bio station 09LS101 promote growth of aquatic macrophytes, and the DO regime is affected during periods of growth and senescence of these plants.

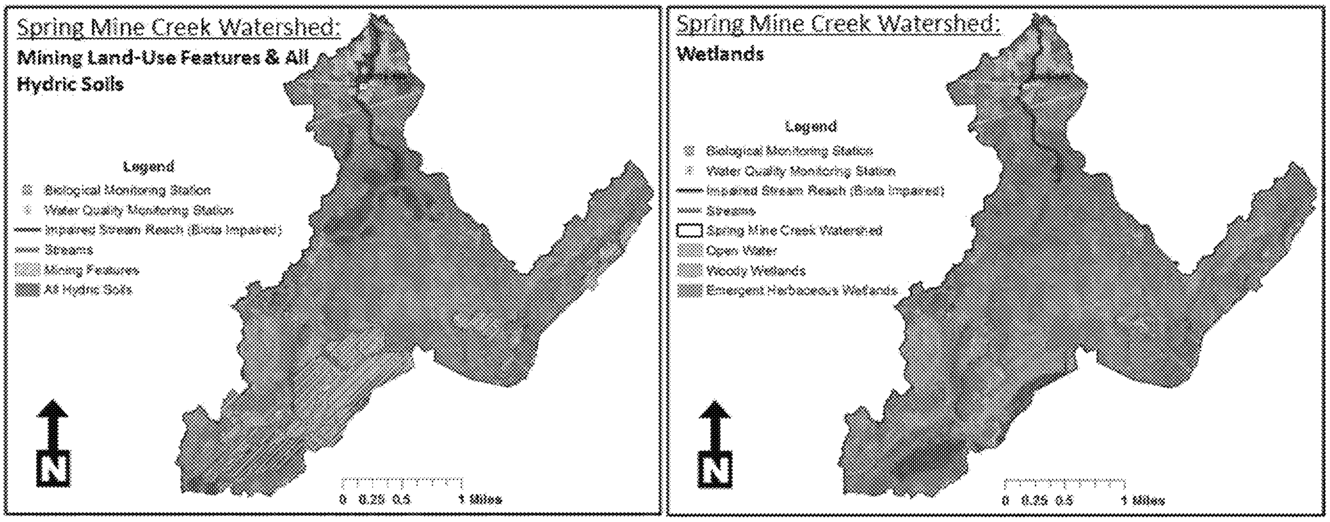


Figure BLANK: Maps of Spring Mine Creek drainage area showing locations of all hydric coils and mine features (left) and wetland features (right).

Biological Response to Dissolved Oxygen Stressor

The fish community at station 09LS101 of Spring Mine Creek consists primarily of species that are often found in low gradient wetland streams. Generally, the species observed at this station range from "neutral" to highly tolerant in terms of their tolerance to low dissolved oxygen conditions. Brook stickleback, central mudminnow, blacknose shiner, and pearl dace are examples of fish species observed at station 09LS101 that tend to occupy or dominate stream reaches with low dissolved oxygen content. Central mudminnow and brook stickleback are often prevalent in streams with low dissolved oxygen levels. Combined, these two species accounted for a relatively large percentage (25% and 50%) of the overall fish community over the two sampling visits. No fish species known to be sensitive to low DO concentrations were observed during the two sampling events. However, the presence of "neutral" species such as white sucker, creek chub, and burbot in this stream suggest that DO concentrations in Spring Mine Creek are not low enough to exclude all but tolerant species.

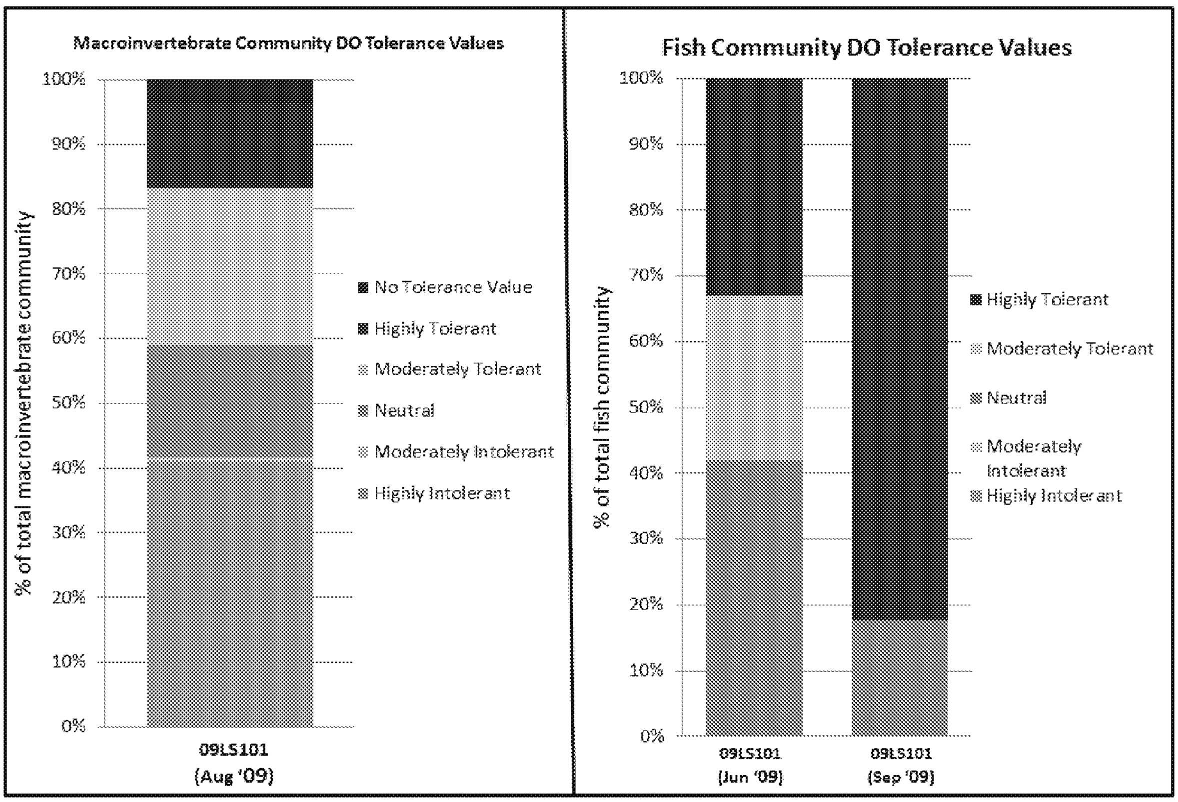
The fish metric *TolPct* (% of total individuals that are tolerant species) has shown to be responsive to DO flux based on quantile regression using a Minnesota statewide data set (Laing 2014, personal communication). As DO flux increases, the percent of tolerant individuals also tends to increase. Spring Mine Creek supports a higher percentage of tolerant fish than most other SLRW sites of the same fish IBI class. Over 72% of the fish sampled in the original fish survey conducted in June of 2009 were tolerant species. The percentage of tolerant fish dropped slightly to 60% in the follow-up survey conducted in September of 2009.

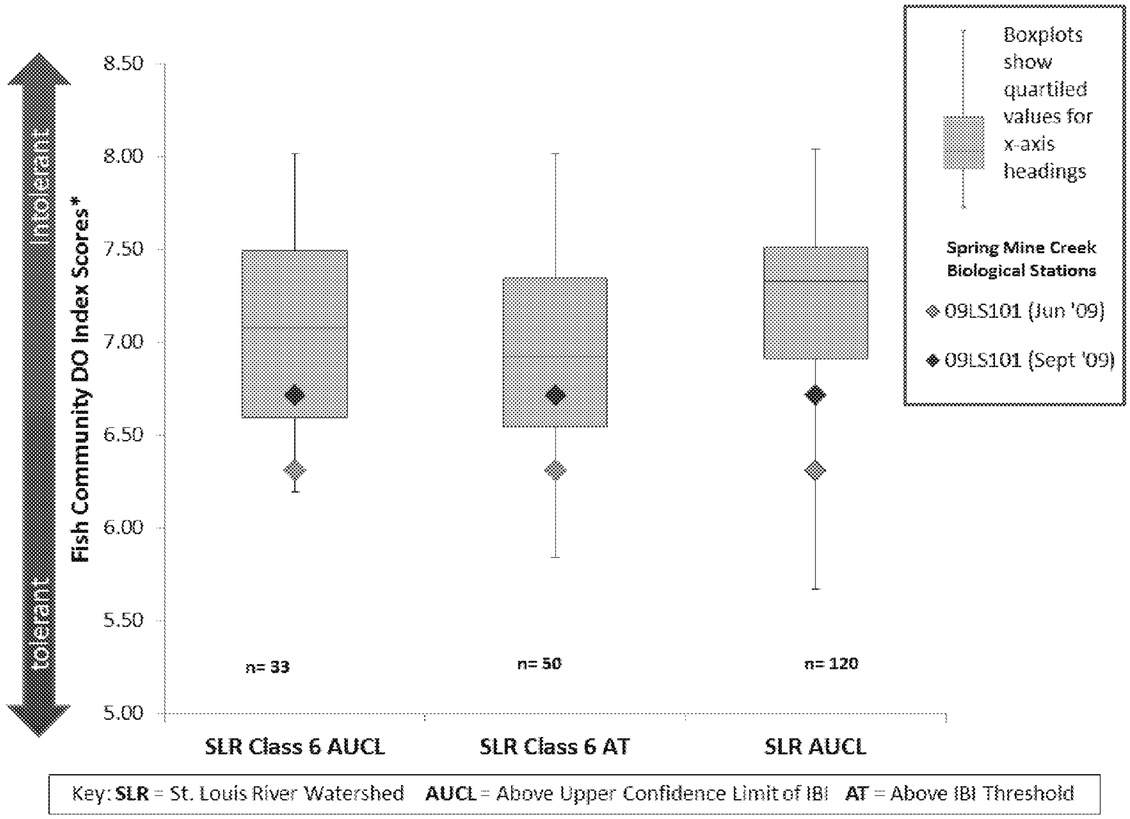
	Median	Min	Max	25th Pctile	75th Pctile
Spring Mine Ck	68.4	60.2	72.7	n/a	n/a
Class 6 AT (n=53)	52.4	3.7	86.8	32.4	70.0
Class 6 AUCL (n=46)	53.3	3.7	86.8	34.1	69.1

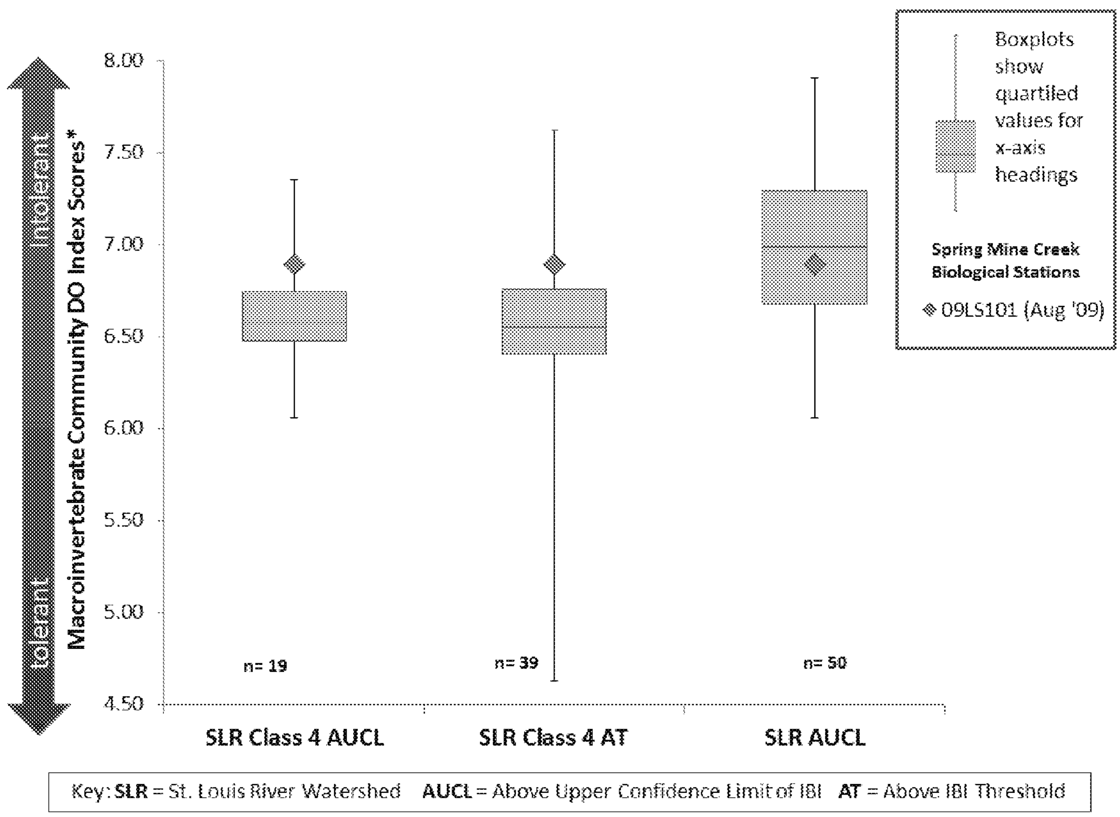
The macroinvertebrate community did contain several taxa that are considered highly intolerant or moderately intolerant of low dissolved oxygen conditions. The freshwater amphipod *Gammarus* was the most abundant taxa represented in the sample, accounting for 41% of the total organisms that were identified and counted. Although members of the genus *Gammarus* are often tolerant of other stressors (nutrients, ionic strength, suspended sediment), they are known to be sensitive to low dissolved oxygen concentrations.

Other than *Gammarus*, no additional low DO intolerant taxa were observed in Spring Mine Creek at station 09LS101. Overall, most of the macroinvertebrate taxa present in Spring Mine Creek are not sensitive to low DO environments. A total of 9 low DO tolerant taxa were observed, and of these, 5 can be considered “very tolerant” of low DO. The total number of taxa sampled at this station was 37, so nearly 25% of the total taxa observed are tolerant of low dissolved oxygen conditions.

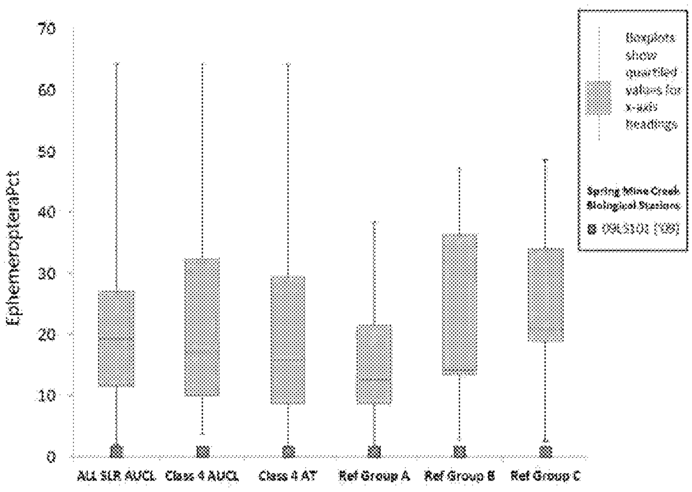
Summary

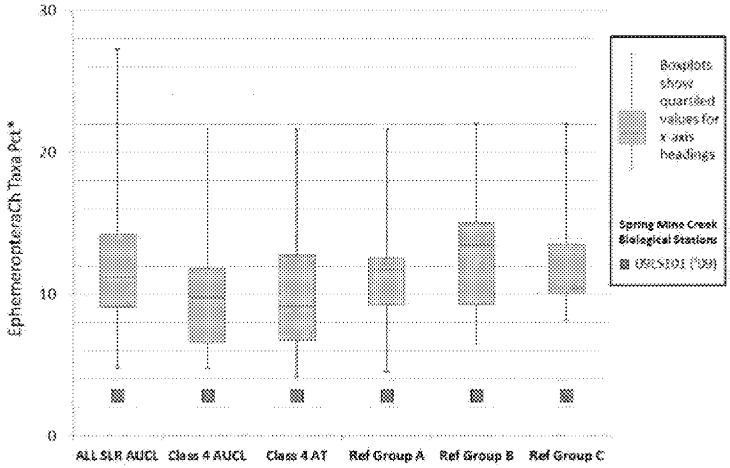


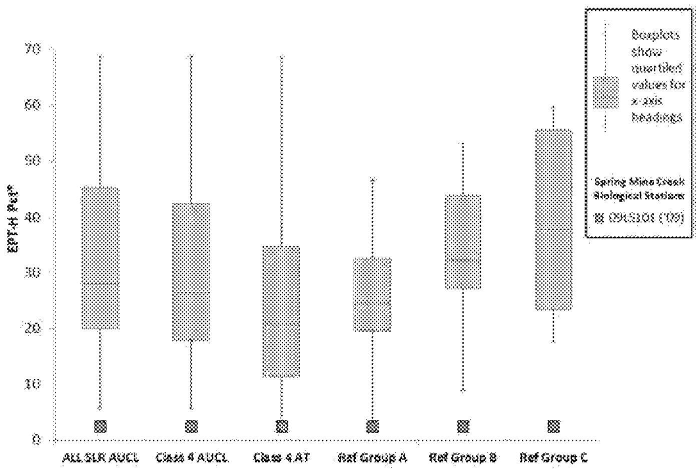


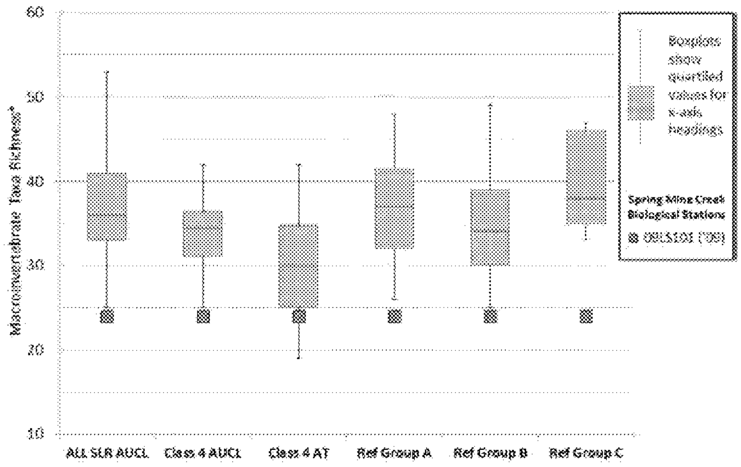


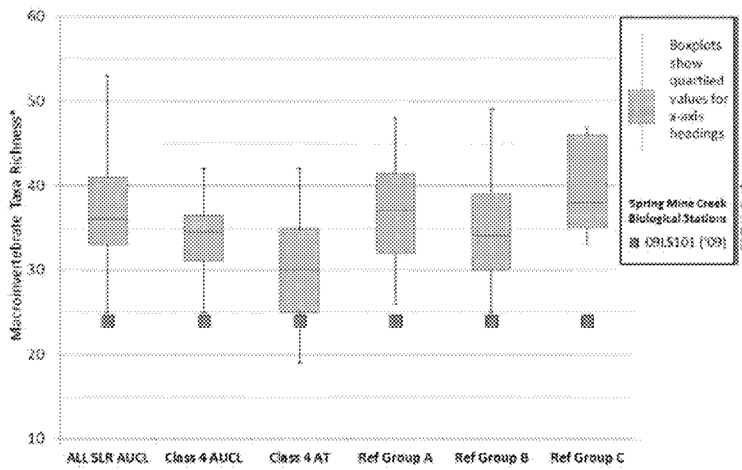
Ionic Strength

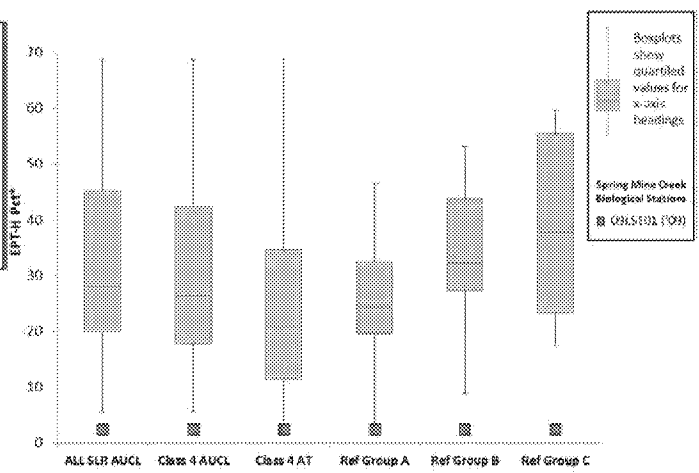

EphemeropteraPct
70
60
50
40
30
20
10
0
ALL SLR AUCL
Class 4 AUCL
Class 4 AT
Ref Group A
Ref Group B
Ref Group C
Boxplots show quartiled values for x-axis headings
Spring Mine Creek Biological Stations
09LS101 ('09)


EphemeropteraCh Taxa Pct*
30
20
10
0
ALL SLR AUCL
Class 4 AUCL
Class 4 AT
Ref Group A
Ref Group B
Ref Group C
Boxplots show quartiled values for x-axis headings
Spring Mine Creek Biological Stations
09LS101 ('09)


EPT-H Pct*
70
60
50
40
30
20
10
0
ALL SLR AUCL
Class 4 AUCL
Class 4 AT
Ref Group A
Ref Group B
Ref Group C
Boxplots show quartiled values for x-axis headings
Spring Mine Creek Biological Stations
09LS101 ('09)


Macroinvertebrate Taxa Richness*
60
50
40
30
20
10
ALL SLR AUCL
Class 4 AUCL
Class 4 AT
Ref Group A
Ref Group B
Ref Group C
Boxplots show quartiled values for x-axis headings
Spring Mine Creek Biological Stations
09LS101 ('09)


Macroinvertebrate Taxa Richness*
60
50
40
30
20
10
ALL SLR AUCL
Class 4 AUCL
Class 4 AT
Ref Group A
Ref Group B
Ref Group C
Boxplots show quartiled values for x-axis headings
Spring Mine Creek Biological Stations
09LS101 ('09)


EPT-H Pct*
70
60
50
40
30
20
10
0
ALL SLR AUCL
Class 4 AUCL
Class 4 AT
Ref Group A
Ref Group B
Ref Group C
Boxplots show quartiled values for x-axis headings
Spring Mine Creek Biological Stations
09LS101 ('09)

Sulfate

Habitat

Ely Creek

Habitat

Dissolved Oxygen

Embarrass River

Dissolved Oxygen

Habitat

Ionic Strength

Sulfate

Metals -- Aluminum / Copper

BOD

Virginia Mesabi Range Watershed Zone

Biological impairment listings within the Virginia Mesabi Range (VIR) watershed zone include two segments of Elbow Creek and the outlet stream of Manganika Lake (Manganika Creek), which is a very short tributary to the East Two River. The watersheds of these two streams have been dramatically altered due to mining land-uses. While Elbow Creek still remains a free-flowing stream has retained most of its original length, much of the stream is channelized and routed around a series of mine pits and waste rock stockpiles. It flows through nutrient-impaired Elbow Lake at its mid-point before joining the St. Louis River near the town of Forbes. Elbow Creek has historically received dewatering flow from abandoned mine pits, and is currently the receiving water for the city of Eveleth's wastewater treatment plant (WWTP) effluent.

The watershed area of Manganika Creek has been reduced by 48% due to mining and urban development, which equates to reduction in mean annual flow of 2.86 cubic feet per second (cfs). This reduction in flow has been replaced to some degree by current mine pit dewatering permits in the watershed, which discharge 2.45 cfs to the stream. There are currently plans to expand a mine pit in the vicinity of the creek that will alter additional land in the watershed. The city of Virginia WWTP currently discharges effluent to a tributary of Manganika Lake. Manganika Lake is currently listed as impaired for elevated nutrient concentrations.

The fish impairment on Elbow Creek is limited to a reach upstream of Elbow Lake (pictured in Figure BLANK-2). Fish survey results from this reach show an assemblage dominated by brook stickleback, northern redbelly dace, central mudminnow, and fathead minnow. These species are commonly found in streams with wetland qualities and are all at least somewhat tolerant of low dissolved oxygen conditions. The fathead minnow is considered a "pioneer species," which means they are highly adaptable to streams that are regularly disturbed by a stressor. Darter species and simple lithophils (gravel spawning fish) were absent from the sampling station on this impaired reach, which also factored significantly into the low fish IBI score.

The macroinvertebrate impairment on Elbow Creek includes the reach mentioned above, as well as the reach extending downstream of Elbow Lake to the confluence with the St. Louis River. Monitoring stations on the two reaches were assessed using different M-IBI criteria due to differences in stream gradient and habitat types. The upper reach, which flows through a low gradient wetland area, had a macroinvertebrate community dominated by non-insect taxa – aquatic worms (Oligochaeta), roundworms (Nematoda), pill clams (Pisidiidae), and various chironomid taxa. Four dragonfly taxa and one caddisfly taxa (Ptilostomis) found at this location, but no stonefly or mayfly taxa were present. Overall, no intolerant or sensitive macroinvertebrate taxa were present at this site. The macroinvertebrate community in the lower reach of Elbow Creek was more evenly distributed among the taxa present, and does not appear to be as degraded as the community in upper Elbow Creek. Compared to high-quality sites of the same M-IBI class, this reach of Elbow Creek supported fewer "clinger" taxa and lacked the stonefly taxa that were present at other monitoring sites.

The fish and macroinvertebrate communities found in Manganika Creek are severely degraded. A fish IBI score of 0 out of a possible 100 was recorded for both of the monitoring stations on this stream. Only three fish species were observed; central mudminnow, brassy minnow, and yellow perch. The overall catch in the reach below Manganika Lake was extremely low, as only 13 fish were collected at that station. This fish assemblage represents a dramatic departure from what is typically observed in healthy headwaters streams in northern Minnesota.

The macroinvertebrate community in Manganika Creek was dominated by various chironomid taxa, in particular species from the genera Glyptotendipes and Dicrotendipes. Nearly 70% of the organisms identified were from these two genera, which are well known to be very tolerant of many forms of pollution and habitat degradation. Glyptotendipes sp. are known to be very tolerant of organic pollution, and Dicrotendipes sp. have been linked to streams with moderate to high water temperatures, organic matter, total suspended solids, pH, phosphates, and sulfates (Al-Shami et al, 2010).

Manganika Creek

Dissolved Oxygen

Ionic Strength

Sulfate

TSS / Turbidity

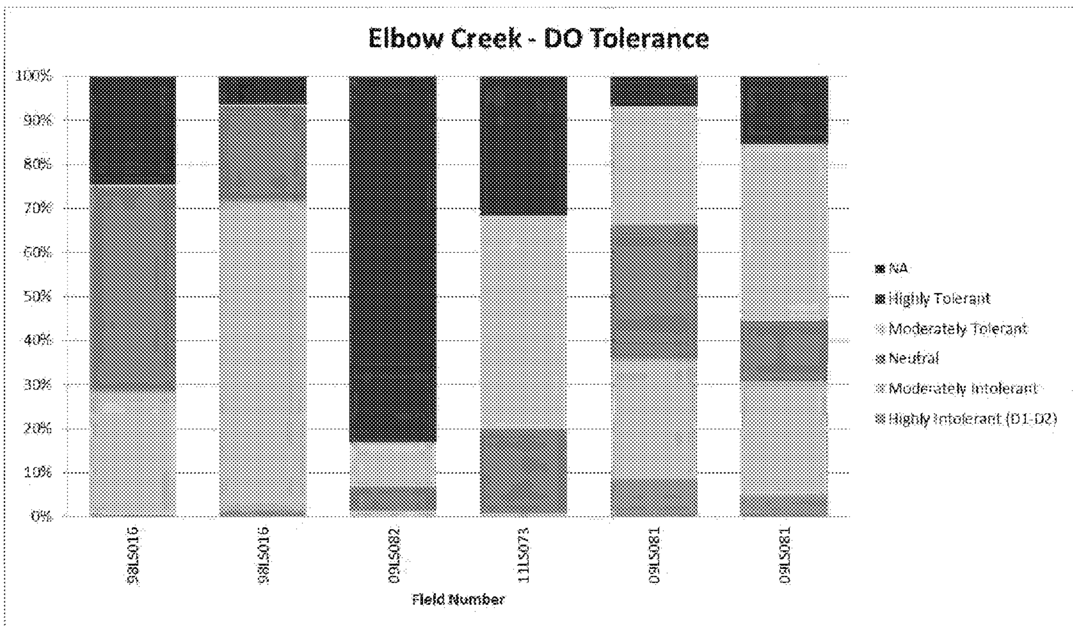
pH

Ammonia

Elbow Creek

Dissolved Oxygen

Low DO-tolerance levels in the macroinvertebrate community of Elbow Creek vary considerably from reach to reach. The headwaters monitoring station (98LS016) between the towns of Eveleth and Leonidas shows a relatively high percentage of organisms that are moderately intolerant of DO, particularly in the most recent sample (2009). A robust population of *Simulium* (black fly) and *Micropsectra* (common name) in both 1998 and 2009 sampling events account for most of the intolerant organisms found at this station. Further downstream, Elbow Creek flows through an expansive wetland area tations 09LS082 is located within



Sulfate

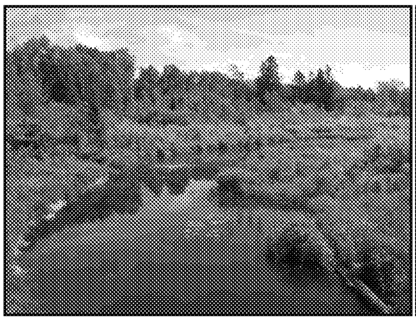
Ionic Strength

Nitrate

Aluminum

West Two McQuade Moraines Watershed Zone

This watershed zone includes two impaired streams, the West Two River below West Two Reservoir, and a tributary to McQuade Lake (Kinney Creek). The reservoir was created in 1964 by U.S. Steel Company and is now listed as impaired for elevated nutrient concentrations. The impoundment is currently permitted to release a minimum of 3 cfs of streamflow into the impaired reach of the West Two River. Headwaters streams in both of these watersheds have been removed or reduced due to the presence of mining land-use. The loss of these headwaters streams, as well as current mine-pit dewatering and impounded reservoirs, has altered the hydrological regime of these streams from their natural state.



The M-IBI impairment on the West Two River is limited to a 5.5 mile reach downstream of the reservoir outlet. The macroinvertebrate community at the impaired sampling location within this reach was dominated by Hirudinea (leeches), which accounted for over 1/3 of the individuals counted. Also common were individuals from the chironomid families Tanytarsus and Dicrotendipes, which are known to be tolerant of streams with elevated nutrient concentrations, low dissolved oxygen, and predominantly fine substrates. Only six EPT taxa were present at this station, and individuals from these there order accounted for a relatively low percentage of the overall community (14%).

The macroinvertebrate community in McQuade Creek is not highly degraded, but M-IBI scores were narrowly below the established impairment threshold which resulted in an impairment listing. Several mayfly taxa (Acerpenna, Baetis) and caddisfly taxa (Cheumatopsyche, Micrasema, Neurclipsis) were present in relatively high numbers in this reach, which is another indication that this stream is probably not severely impacted. The absence of Plecoptera (stonefly) and Odonata taxa (dragonfly) at this site is the primary reason that IBI scores were low enough to list this reach as "impaired." Although this reach does not appear to be as impacted as other impaired waters in the SLRW, potential stressors in this watershed will be further evaluated later in this report.

West Two River

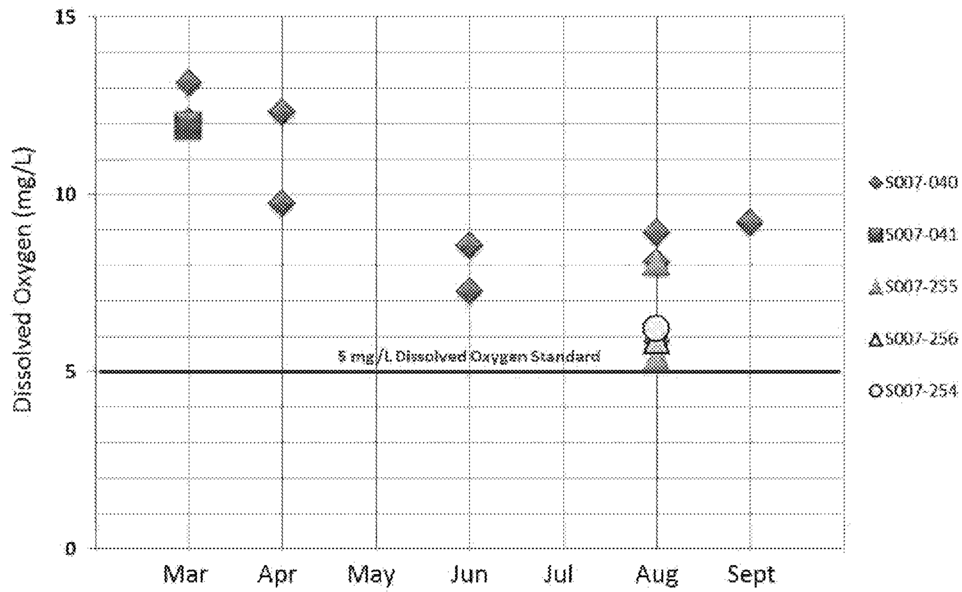
Unnamed Trib to McQuade Lake

Dissolved Oxygen

Available Dissolved Oxygen Data

Instantaneous Measurements

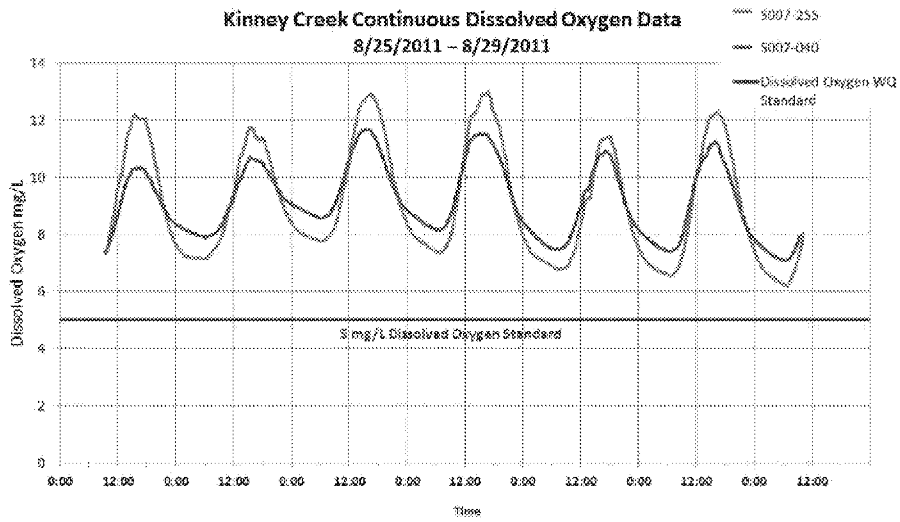
Instantaneous dissolved oxygen data are available for 5 stations on Kinney Creek, although several stations were only visited a single time. The majority of instantaneous DO data were collected at station S007-040, which is co-located with the biological monitoring station that served as the impetus for the impairment listing (09LS074). Based on the available instantaneous data, dissolved oxygen concentrations ranged from approximately 5 mg/l to 9 mg/L during the months spanning June through September (figure BLANK). Dissolved oxygen concentrations in were fairly low at four of the monitoring stations in August of 2013, but none of the results fell below the water quality standard of 5 mg/L.

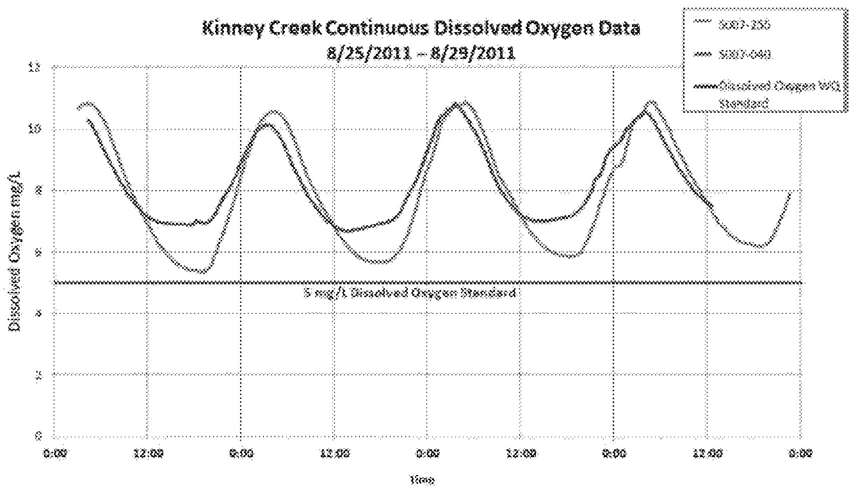


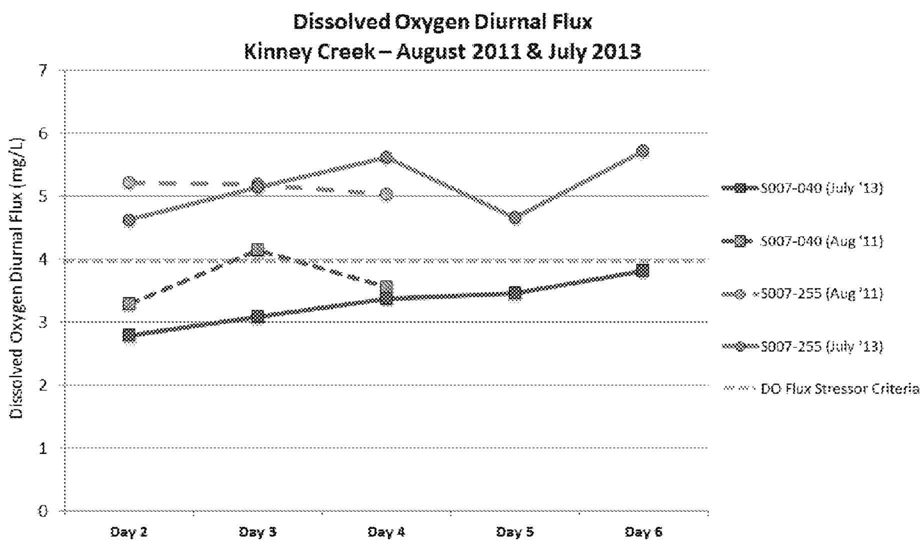
Continuous Dissolved Oxygen Data

Continuous dissolved oxygen monitoring data were collected at two locations on Kinney Creek during the months of July and August in 2011 and 2013. The continuous monitoring sites (S007-040 and S007-255) were co-located with the two biological monitoring stations on the creek in order to better evaluate relationships between the biota and dissolved oxygen regime. Multi-parameter water quality monitoring sondes were deployed for a period of 5-7 days at each site and set to record dissolved oxygen concentrations at 15-minute intervals. The complete dissolved oxygen profiles collected during this monitoring effort are shown in figure BLANK.

Minimum dissolved oxygen concentrations were found to be suitable for supporting warm and coolwater aquatic life at both locations during the two diurnal monitoring periods. Station S007-255 consistently had higher daily maximum and lower daily minimum concentrations than station S007-040, but both sites maintained DO concentrations above the minimum (figure BLANK).







Although the available data does not indicate minimum DO concentrations below water quality targets, diurnal DO flux was quite high at both monitoring stations, particularly S007-255. While these short-term deployments of DO loggers may not have measured low minimum values, the large swings in concentration are probably an indicator that there is a high potential for low DO conditions to occur in the system at some point during the year, depending on streamflow and atmospheric conditions. DO levels can become very low during high temperatures, low flow conditions, or during the fall when algae and other plants begin to senesce.

Wide diurnal fluctuation in DO concentrations can also stress aquatic organisms, mostly due to the physiological stress resulting from swings in DO. The MPCA's River Nutrient Criteria (Heiskary, 2013) lists a diurnal DO flux greater than 4.0 as a stressor variable for streams and rivers of northern Minnesota. Diurnal DO flux in Kinney Creek exceeded 5 mg/L at station S007-255 during both the August 2011 and July 2013 continuous monitoring periods. DO flux was also greater than 4.0 mg/L at station S007-040 in July of 2013, but only for one 24 hour period. Based on the continuous monitoring data available, DO flux can be considered a candidate stressor in Kinney Creek, and may be more problematic than low minimum DO concentrations.

Sources and Pathways Contributing to Dissolved Oxygen Stress

Nutrient enrichment, Chl-a concentrations, and measures of biological oxygen demand (BOD) are all factors in the DO regime of streams and rivers. MPCA has developed nutrient criteria for Minnesota rivers (not yet official state rules) with thresholds for total phosphorous (TP) and several related stressor effects linked to excess nutrients -- high diurnal DO flux, high Chl-a concentrations, and elevated BOD levels. See section BLANK for more information on the river nutrient criteria. Kinney Creek data and the guidelines provided by the river nutrient criteria (in development) can be used to investigate potential pathways and sources causing DO stress.

<u>Total Phosphorous</u>

TP data available for Kinney Creek are limited, with only six results available from a single monitoring station (S007-040). All of the data are from the 2012 monitoring season. The results show elevated TP concentrations (0.160 mg/L) during the spring snowmelt runoff period and considerably lower concentrations throughout the rest of the summer and early fall (avg=0.03 mg/L, max=0.038, min=0.019). Aside from the snowmelt sample, all TP results are below the draft river nutrient criteria of 0.055 mg/L. Additional monitoring may be required to better understand how TP concentrations vary from year to year, but these data indicate that Kinney Creek is not a highly eutrophic stream.

<u>Biological Oxygen Demand</u>

No data available.

<u>Chl-a</u>

No data available.

Biological Response to Dissolved Oxygen Stress

A series of macroinvertebrate metrics were chosen to evaluate linkages between low dissolved oxygen and DO flux and the macroinvertebrate IBI impairment in Kinney Creek. The metrics (listed in table BLANK) have been shown to respond, either negatively or positively, when unfavorable dissolved oxygen conditions for aquatic life are observed. Data from Kinney Creek will be evaluated using these metrics to explore cause and effect relationships between DO flux and biological response.

Table BLANK:

Metric	Predicted Response	Source

Macroinvertebrate Community DO Index	negative	
EPT Taxa	negative	
Taxa Richness	negative	
% Non-Insect Taxa	positive	
Plecoptera	negative	

Macroinvertebrate Community Dissolved Oxygen Index

Macroinvertebrate DO Index scores at the three Kinney Creek biological monitoring stations are compared to scores from high-quality stations in figure BLANK. DO index scores at Kinney Creek stations are comparable to or more favorable than many of the index scores observed at comparable reference streams in the SLRW (figure BLANK). These results indicate that the macroinvertebrate community of Kinney Creek is not highly tolerant of low dissolved oxygen conditions. However, the variability in the DO index score at station 09LS074 between the 2009 and 2011 sampling events show a potential for the community to shift to more DO tolerant organisms. Over 75% of class 3 MIBI stations in the SLRW with a passing IBI score had a higher DO index value than the 2011 visit to station 09LS074. A shift in the macroinvertebrate community away from mayflies (Baetis) to more tolerant amphipod crustacean (Hyallela) at station 09LS074 was responsible for the drop in DO index scores observed in the two sampling events.

The DO index score at station 11LS075 was very good; scoring well above the 75th percentile values of comparable reference streams (Figure BLANK). This station had the higher dissolved oxygen flux (> 5.5 mg/L) of the two biological monitoring stations, so it does not appear that DO flux is negatively influencing DO index values in Kinney Creek. The DO index scores are based on an organism's sensitivity to low dissolved oxygen, and DO flux was not considered in the development of the index scores. Therefore, the DO index score may not be a fully appropriate metric to evaluate a DO flux stressor.

EPT Taxa Richness and Overall Taxa Richness

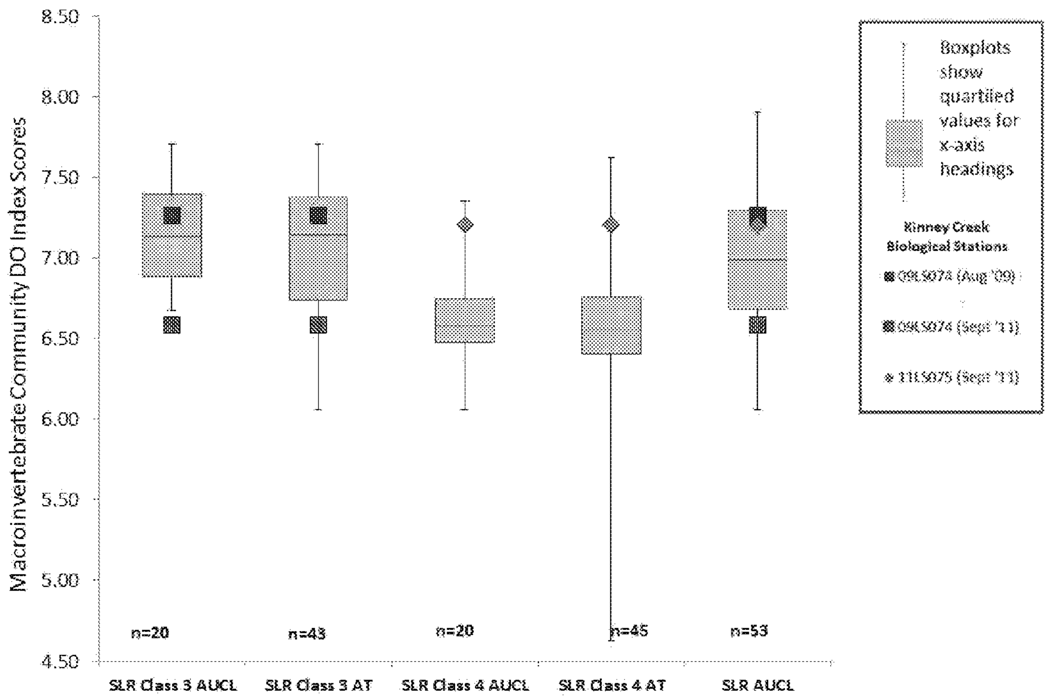
EPT taxa richness and overall taxa richness are known to decline in streams with low DO concentrations or high DO flux (Source). The number of EPT taxa observed at Kinney Creek monitoring stations ranged from 11 to 16 taxa. In comparison, the median EPT taxa richness at reference sites ranged from 10 to 21 taxa (figure BLANK). The station with the lowest EPT taxa richness, 11LS075, is still comparable to other streams in the SLRW with passing MIBI scores. EPT taxa richness at Kinney Creek sites generally fall within the 25-75th percentile range of

Nearly 66% of the macroinvertebrate individuals sampled at station 09LS074 (2009 sample) were from EPT families. EPT taxa that were abundant at this station include *Baetis* and *Acerpenna* mayflies, caddisflies from the genus *Cheumatopsyche*, *Neureclipsis*, *Hydropsychidae*, and *Micrasema*. No Plecopteran (stonefly) taxa were observed at this station, or any other station in Kinney Creek.

Overall macroinvertebrate taxa richness in Kinney Creek is lower than many of the comparable reference streams in the SLRW (figure BLANK). Taxa richness at the two monitoring sites ranged from 24 to 33 taxa. Both monitoring stations on Kinney Creek were at or below the 25th percentile taxa richness values of comparable reference streams.

Insect Taxa %

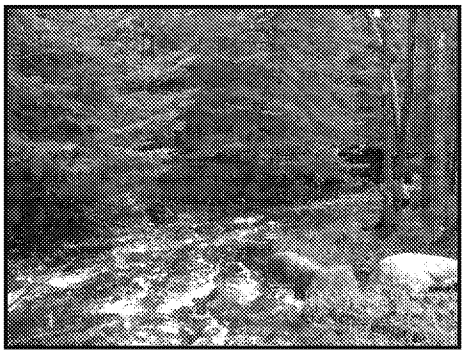
Increases in DO flux can lead to an increase in less desirable non-insect aquatic species such as aquatic worms (Oligochaeta), fly larvae (e.g., some Chironomidae {midges}), and snails. Between 82-88% of the macroinvertebrate taxa observed in Kinney Creek are considered aquatic insects (figure BLANK). The median values for the reference sites compiled in figure BLANK range from 85-90%, with upper quartile values extending into the 92% range.



Key: **SLR** = St. Louis River Watershed **AUCL** = Above Upper Confidence Limit of IBI **AT** = Above IBI Threshold

Swan River – Hibbing Watershed Zone

Impaired streams within this watershed zone include East Swan Creek, a designated trout stream south of the city of Hibbing, and a mainstem reach of the Swan River, just above its confluence with the St. Louis River. Portions of this watershed zone have been highly modified due to urban development and mining activities. Many of the streams in this region of the SLRW receive effluent from municipal wastewater treatment plants (WWTP) and abandoned iron ore mining pits. Urban impacts, such as an increase in impervious surfaces, stream channelization, and pollutants from road runoff also need to be considered as potential stressors in this watershed zone. Elevated turbidity and total suspended solids (TSS) concentrations are also known problems in several streams in this region. These potential stressors will be covered in detail in the water quality section of this report, and additional information specific to turbidity and TSS can be found in the case study presented in Appendix BLANK.



East Swan Creek originates from Bryan Lake and several other small tributary streams within the city limits of Hibbing. Headwaters tributaries of this creek course through many disturbed areas, including high density housing developments, golf courses, junkyards and auto salvage lots, and commercial shopping centers. This area of Hibbing is growing rapidly and becoming increasingly urbanized. Downstream of Hibbing, East Swan Creek receives a continuous, year round discharge of treated wastewater from the Hibbing WWTP. Specific details on the discharge rates and water quality concerns associated with this discharge to the creek will be discussed in the Hydrology and Water Quality component sections of this SID report.

East Swan Creek

East Swan Creek is currently listed as impaired for poor macroinvertebrate IBI scores. The most common macroinvertebrates observed in the impaired reach of East Swan Creek include a variety of pollution tolerant chironomid taxa (Polypedilum, Cladotanytarsus, Tanytarsus), aquatic worms (Oligochaeta), and several mayfly and caddisfly taxa that are often present in moderately degraded habitats (Hydropsyche, Baetis). Nearly 60% of the taxa observed at the impaired biological monitoring site are considered tolerant of pollution or disturbance (based on tolerance data developed for MN). The impaired site scored poorly in the Hilsenhoff Biotic Index, which may be an indication that the macroinvertebrate assemblage as a whole is tolerant of organic pollution.

Temperature

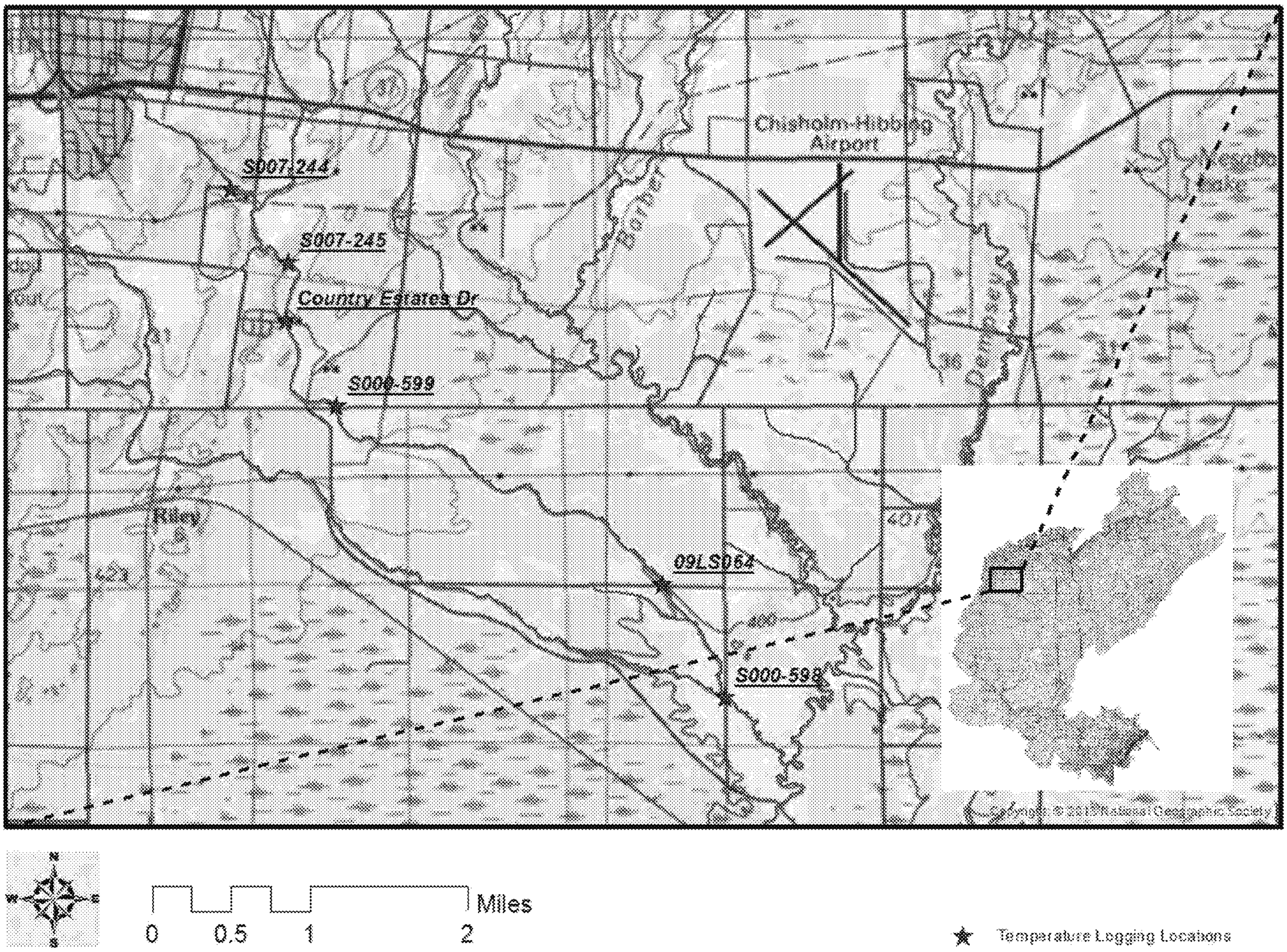


Figure X: HOBO logger locations on East Swan Creek

Temperature data was collected at six sites on East Swan Creek: S007-244 at O'Rourke Road, S007-2145 at River Creek Drive, the Country Estates Drive crossing, S000-599 at Highway 16, 09LS064 at Koivu Road, and S000-598 at Swinnerton Road. Only data between June 1 and August 31 were analyzed – when stream temperatures are most likely to exceed the stress threshold for coldwater-sensitive macroinvertebrate species.

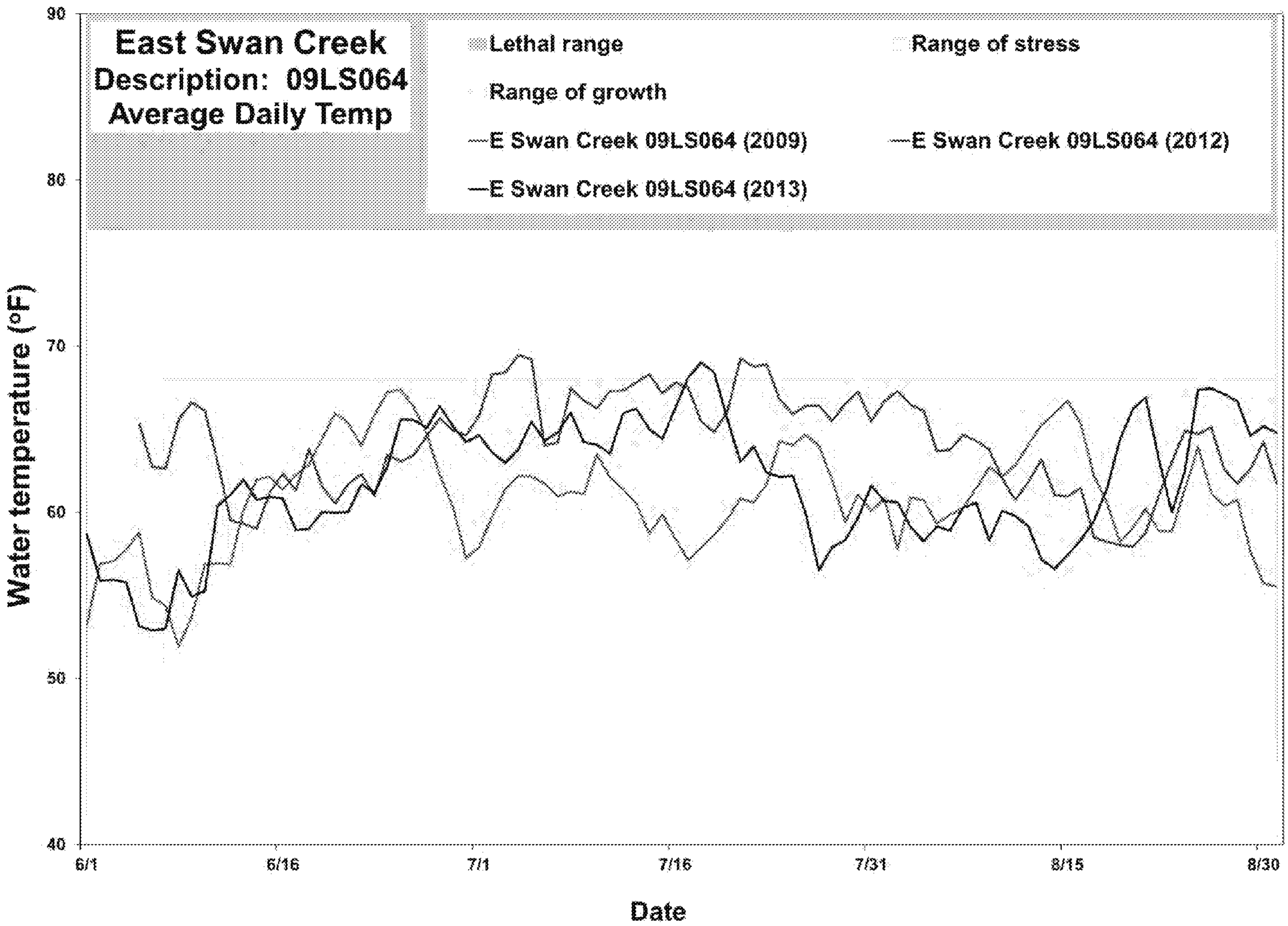


Figure X: Average daily temperatures for 2009, 2012, and 2013 at 09LS064, the impaired biosite on East Swan Creek

The East Swan Creek macroinvertebrate IBI impairment is based on sampling results from 09LS064.The average daily temperature in East Swan Creek at 09LS064 is cool and remarkably stable (Figure X), possibly due to the relatively large contribution of summer flow that originates at the wastewater plant. Only 2% of the average daily temperatures exceeded the stress threshold during the summers of 2009, 2012, and 2013 (6 days out of 272 recorded). Average stream temperatures were cool even during 2012 (see red line in Figure X), which was a much warmer-than-normal summer. By contrast, the average daily temperatures upstream of the wastewater plant were much warmer and more erratic (see Figure X). This suggests that the discharge of the wastewater plant has a stabilizing and cooling effect on the temperature of the stream.

We also compared East Swan Creek temperatures to those of a nearby, non-impaired biological monitoring site. Spider Muskrat Creek, 25 miles away, is a coldwater stream and macroinvertebrate IBI scored above the upper confidence limit. As can be seen from Figure X, East Swan Creek's temperature regime is actually cooler than that of Spider Muskrat Creek. 18% of the daily average temperatures in Spider Muskrat Creek exceeded the stress threshold (17 days out of 92). Based on this analysis, it is clear that other factors are limiting the macroinvertebrate community in East Swan Creek and we recommend that temperature should not be considered a stressor for East Swan Creek.

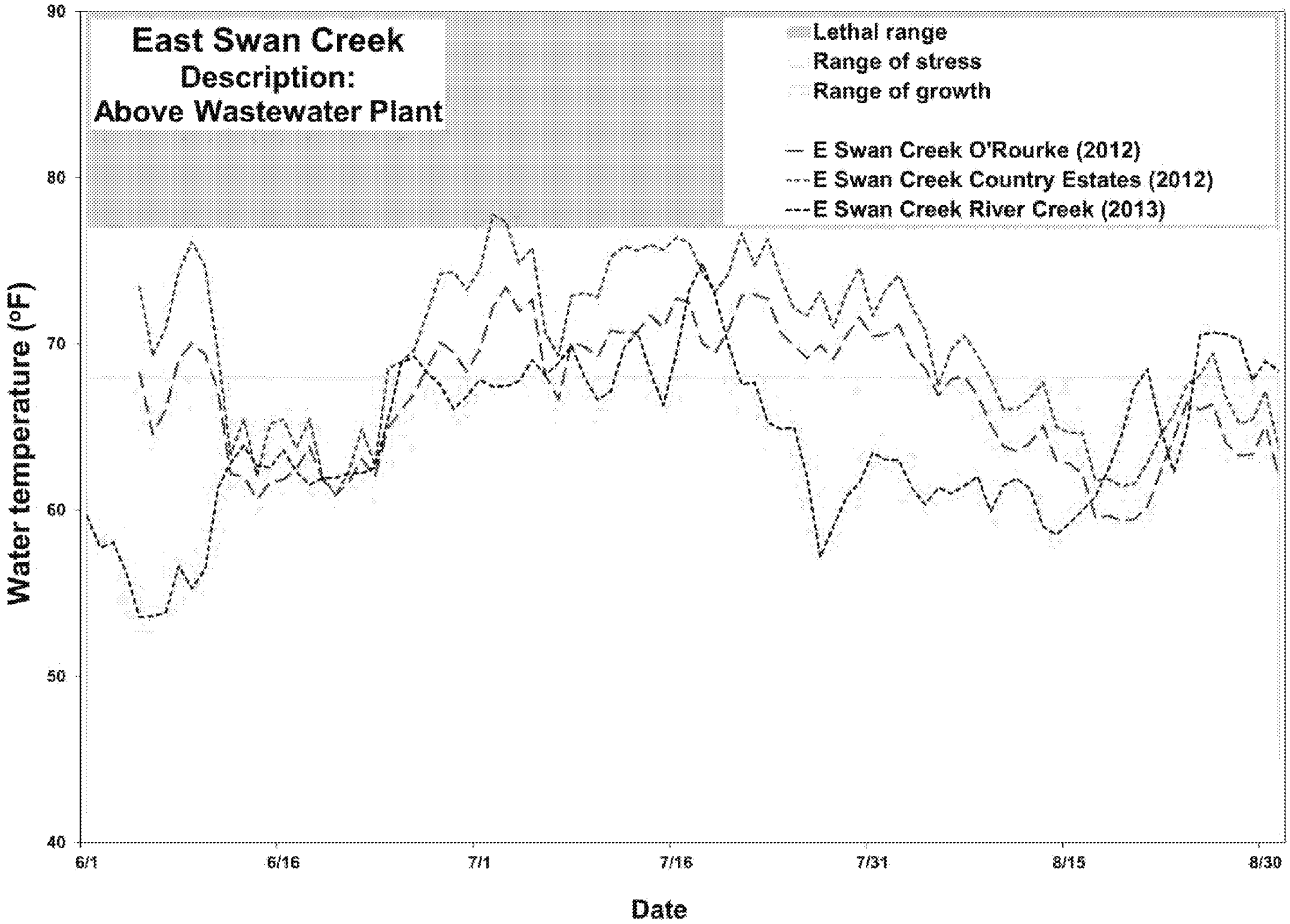


Figure X: Average daily temperatures in East Swan Creek upstream of the wastewater treatment plant

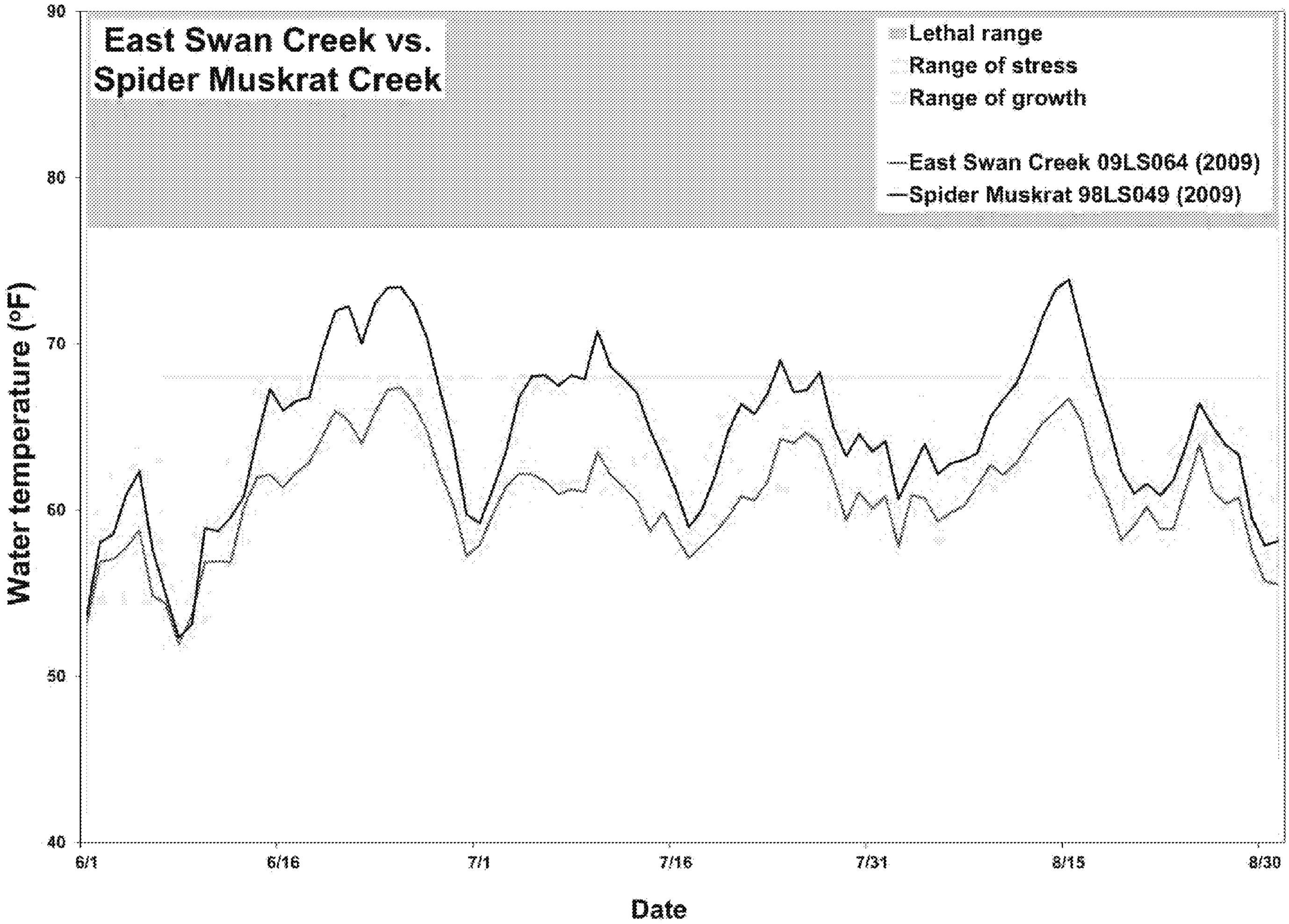


Figure X: East Swan Creek average daily temperatures in 2009, compared to non-impaired Spider Muskrat Creek during the same year

Dissolved Oxygen

TSS / Turbidity

Ionic Strength

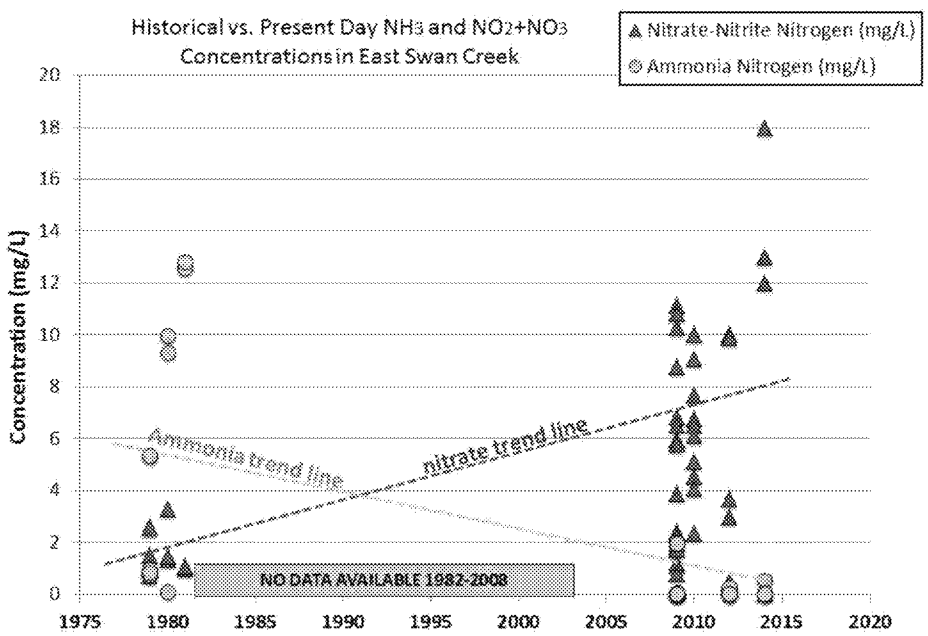
Nitrogen (Nitrate and Ammonia)

Elevated nitrogen levels have been documented in East Swan Creek as far back as 1979. Between the years 1979-1981, monitoring data shows elevated ammonia-N concentrations (up to 13 mg/L) downstream of the Hibbing WWTP, but nitrate concentrations at this time were relatively low (avg. less than 2 mg/L). More contemporary data from 2009-2014 shows a reversal of this trend, with higher nitrate concentrations (up to 18 mg/L) and very low ammonia concentrations, averaging less than 1 mg/L (figure BLANK).

Prior to May 31st, 2008 the city of Hibbing operated two separate WWTPs (North & South). The city of Hibbing wanted to join and modernize the facilities to reduce treatments costs and avoid redundant upkeep costs. A non-degradation review approved by the MPCA allowed the north WWTP to be shut down and the flow rate from the south WWTP expanded to 4.5 MGD. The expansion of the south WWTP to 4.5 MGD also introduced stringent cBOD5 and ammonia limits in order to be protective of the receiving water of East Swan Creek. The Hibbing WWTP was assumed to be the dominant source of nitrogen to East Swan Creek.

In order to meet the cBOD5 and ammonia limits, a nitrifying WWTP design was created for the expanded south Hibbing WWTP. A nitrifying WWTP uses microbial population dynamics to convert ammonia to nitrate. The decrease in ammonia concentrations and the increase in nitrate concentrations in East Swan Creek from 1982 to present can be explained by the Hibbing WWTP fully nitrifying its effluent; effectively converting nitrogen species from ammonia to nitrate.

Historically, ammonia nitrogen may have been a stressor to aquatic life in East Swan Creek. Since 2008, ammonia levels in the creek have decreased substantially and are no longer considered a threat to fish and macroinvertebrate populations. Therefore, only the nitrate form of nitrogen will be evaluated as a candidate cause of the impaired macroinvertebrate community.



Nitrate

Nitrate-Nitrite nitrogen (nitrate) sampling results are available for six stations along East Swan Creek. The data were collected primarily between the years of 1979 -1981 and more recently, 2009 – 2014. The results of these sampling efforts are shown in figure BLANK. Nitrate concentrations in East Swan Creek peak during baseflow (low flow) conditions during the late summer, early fall, and mid-winter seasons. Levels as high as 18 mg/L have been recorded (station S000-589, February 2014) and concentrations in the range of 8-12 mg/L are common during summer and fall baseflow periods. Historic data (1979-1981) generally show lower nitrate concentrations, which is most likely due to the different effluent treatment methods that were used at the Hibbing WWTP during this period of time (see section BLANK).

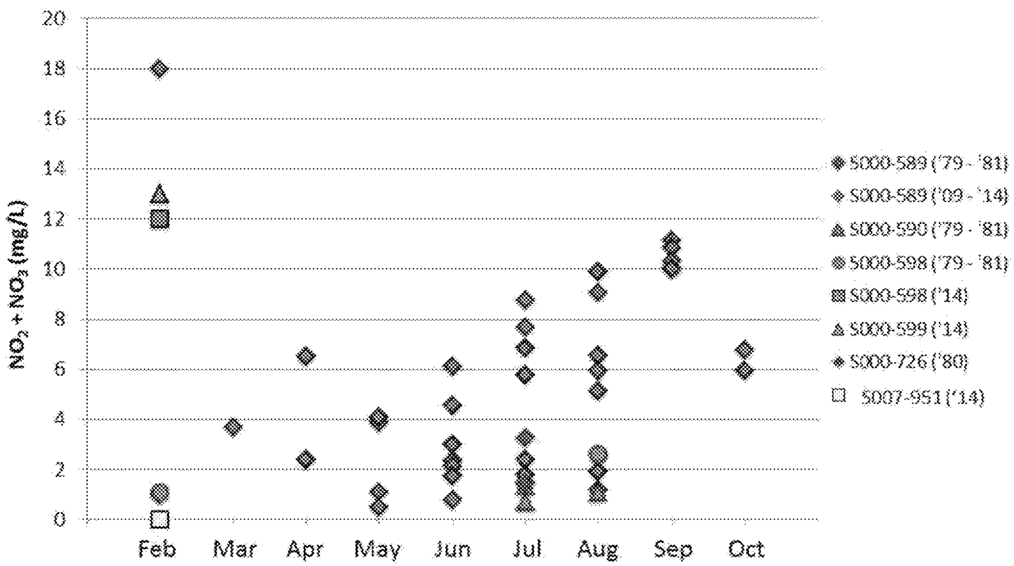


Figure BLANK:

In February of 2014, several samples were collected in a longitudinal pattern along East Swan Creek to identify potential sources and pathways of nitrate within the watershed. Four stations were sampled in the lower ½ of the watershed where elevated nitrate concentrations had been previously observed. Two of these stations, S007-951 and S007-599 were specifically chosen to bracket the location where effluent from the Hibbing WWTP enters East Swan Creek (see map in figure BLANK). The results of the longitudinal sampling clearly show that effluent from the WWTP is the primary source of nitrate entering East Swan Creek. Results from the stations above and below the WWTP outfall show an increase from < 0.05 mg/L above the discharge point to 13 mg/L immediately downstream of the discharge (figure BLANK). Approximately 2.5 miles downstream from the WWTP discharge at station S000-589, nitrate concentrations were even higher (18 mg/L). Additional sources of nitrate between the WWTP and this station are unknown. The increase in nitrate concentrations between these two stations may be the result of in-stream nitrification processes. At station S000-598, 3.3 miles downstream of the WWTP discharge, nitrate concentrations decreased slightly to 12 mg/L.

Nitrogen uptake at 98LS014

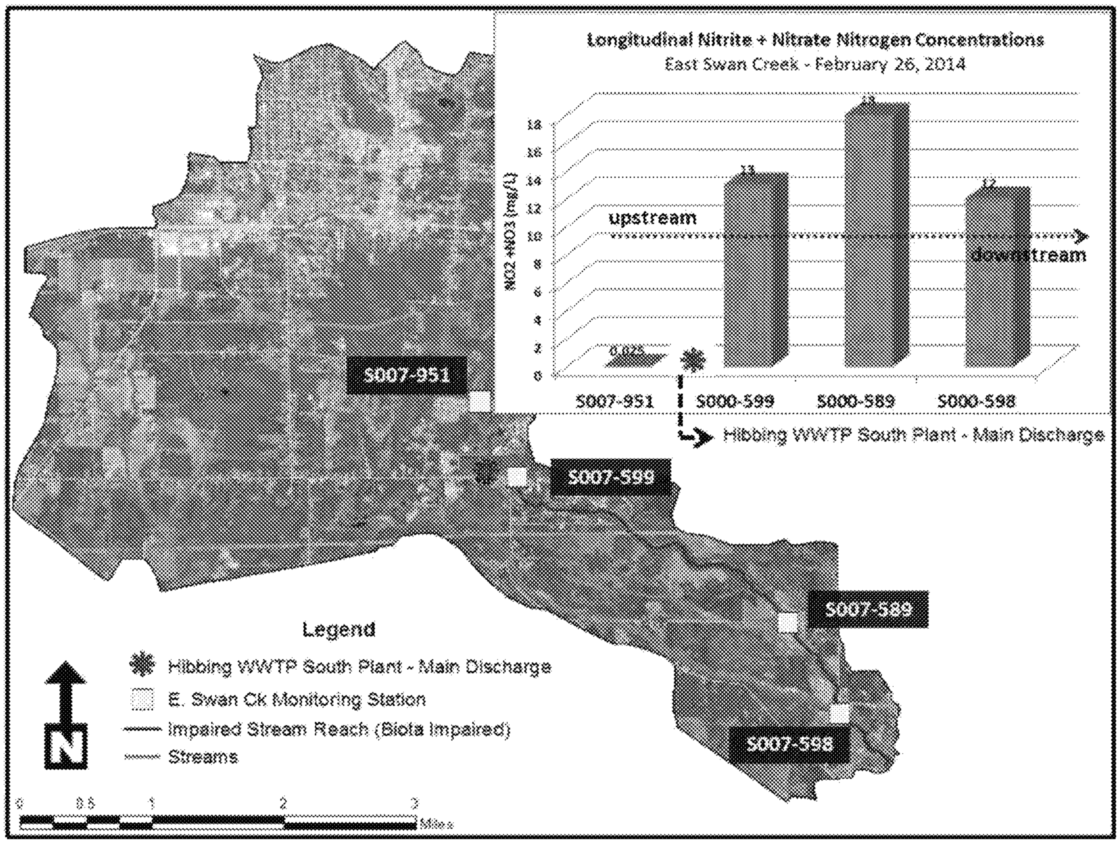


Figure BLANK:

During extreme low flow conditions, effluent discharge from the WWTP accounts for a large portion of the streamflow in East Swan Creek. Upstream of the WWTP, streamflows are generally <1 cubic feet per second (cfs) during low flow periods, which was the case during the February 2014 longitudinal sampling event and other visits to East Swan Creek in late summer or early fall months. Based on permitting reports from the Hibbing WWTP, average discharge rates to East Swan Creek are in the range of 4-5 cfs for most of the year. In wet periods, such as spring snowmelt or large rain events, discharge to the creek can increase to 15-20 cfs. During baseflow conditions, it is likely that wastewater effluent from the Hibbing WWTP accounts for more than 80% percent of the flow in lower East Swan Creek where the biological monitoring stations are located.

Biological Effects of Elevated Nitrate in East Swan Creek

Macroinvertebrate data from four biological monitoring stations are available to evaluate the potential impact of elevated nitrate concentrations in East Swan Creek. The three stations on the mainstem of East Swan Creek are all located downstream of the WWTP influence. In addition to the continuous discharge from the WWTP, there are several wastewater ponds that may be contributing legacy impacts from several overflows that have occurred at this WWTP in the past. Station 09LS063 is located on a tributary to East Swan Creek and is not impacted by WWTP discharge. For more information on these monitoring sites, including a detailed map of site locations, refer to the map on page BLANK.

Nitrate tolerance indicator values (NTI) have been developed by Chirhart (2014) for most macroinvertebrate taxa that have been observed in Minnesota streams. For more information on NTI development, refer to section BLANK. Individual and community based NTI values will be used in this section to evaluate the degree to of nitrate tolerance exhibited by macroinvertebrate taxa in East Swan Creek.

NTI Community Index Scores

Community-based macroinvertebrate NTI values for East Swan Creek monitoring stations are shown in figure BLANK along with quartiled values from statewide, northern coldwater MIBI class, Lake Superior (LS) basin, and St. Louis River watershed monitoring stations. In East Swan Creek, the two stations closest to the WWTP produced the highest NTI scores, which means that nitrate-tolerant macroinvertebrate taxa were more prevalent at those monitoring locations. Station 09LS064 clearly registered the highest NTIV score of all sites sampled on East Swan Creek, and the score seems to be consistently high based on the close agreement between 2009 and 2013 sampling events. NTI scores at 09LS064 were well above the 75th percentile values for all of the data sets used for comparative purposes (figure BLANK). Chemistry results also support 09LS064 as a station of concern for nitrate toxicity, as it recorded the highest nitrate concentration (18 mg/L) during the longitudinal sampling event conducted during the winter of 2014.

The NTI result from station 98LS014 is also elevated compared to values from stations included in the statewide, LS basin, and St. Louis River watershed data sets shown in figure BLANK. Nitrate concentrations were 10 mg/L at the time of sampling (July 1998). As mentioned earlier, station 98LS014 is located just downstream of the main discharge point for the Hibbing WWTP. However, nitrate concentrations during the 2012 longitudinal sampling event were actually higher at station 09LS064 (2.5 miles downstream). Based on the available data, the WWTP is the major source of nitrogen in East Swan Creek, but nitrate concentrations and the impact to aquatic life may reach a peak a short distance (1-3 miles) downstream of the discharge point.

Nitrate tolerant macroinvertebrate taxa accounted for a large percentage of the overall population at stations 09LS064, and to a somewhat lesser extent, at 98LS014 as well. In 2009, over 71% of the macroinvertebrate community at 09LS064 consisted of taxa that can be considered tolerant of elevated nitrate concentrations. In 2013, the percentage of nitrate tolerant individuals at this station decreased slightly to 60%. At 98LS014 (sampled in 1998), nitrate tolerant macroinvertebrate individuals accounted for 59% of the total community sampled. Each of the results at both stations is above the 75th percentile value observed at other stations in the northern coldwater MIBI class and other regional reference sites (figure BLANK). Based on available data, it can be concluded that the reach of East Swan Creek from the WWTP downstream 2-3 miles supports a macroinvertebrate community with a relatively high percentage of nitrate tolerant individuals compared to other monitoring sites in Northeastern Minnesota.

Data from the East Swan Creek tributary station (09LS063) and Swinnerton Road station (13LS105) had lower percentages of nitrate tolerant macroinvertebrates. The tributary stream, with no upstream point source discharge and very low nitrate concentrations (n=22, avg = <0.05 mg/L, max = 0.13 mg/L), supported a macroinvertebrate community in which 46% of the individuals sampled can be considered nitrate tolerant. Station 13LS105, located on the mainstem of East Swan Creek approximately 3.3 miles downstream of the WWTP, had 49% nitrate tolerant individuals in a 2013 sampling event. While the differences between these two sites and others closer to the WWTP do not seem significant, they do support a gradient of biological effect that decreases with distance from

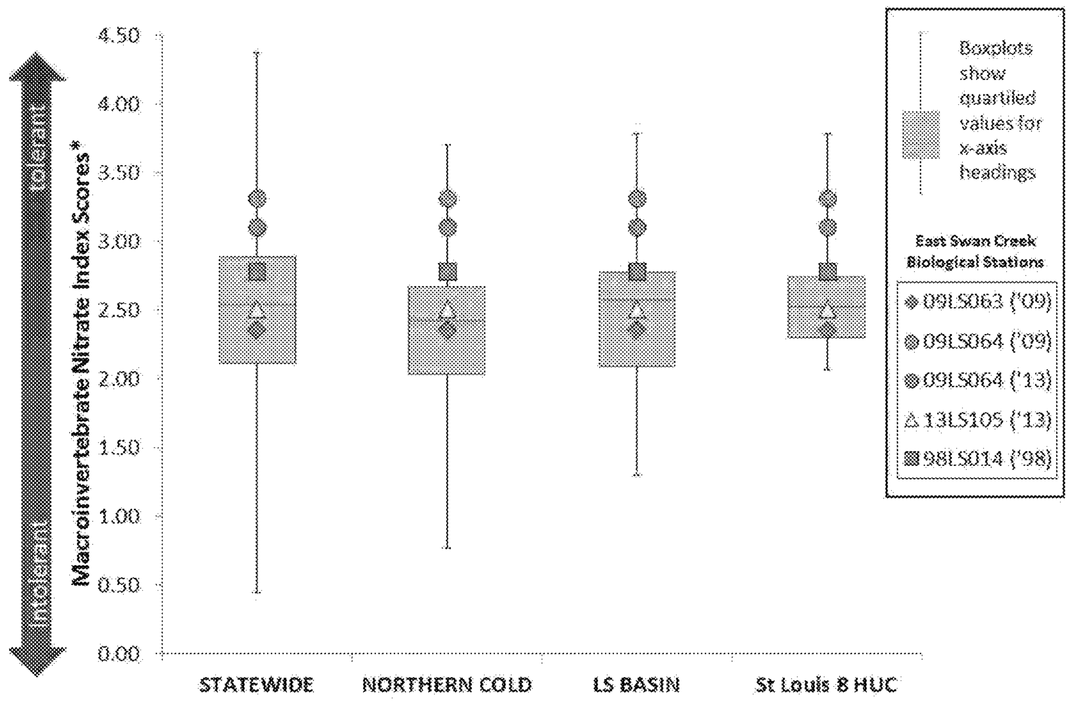


Figure BLANK:

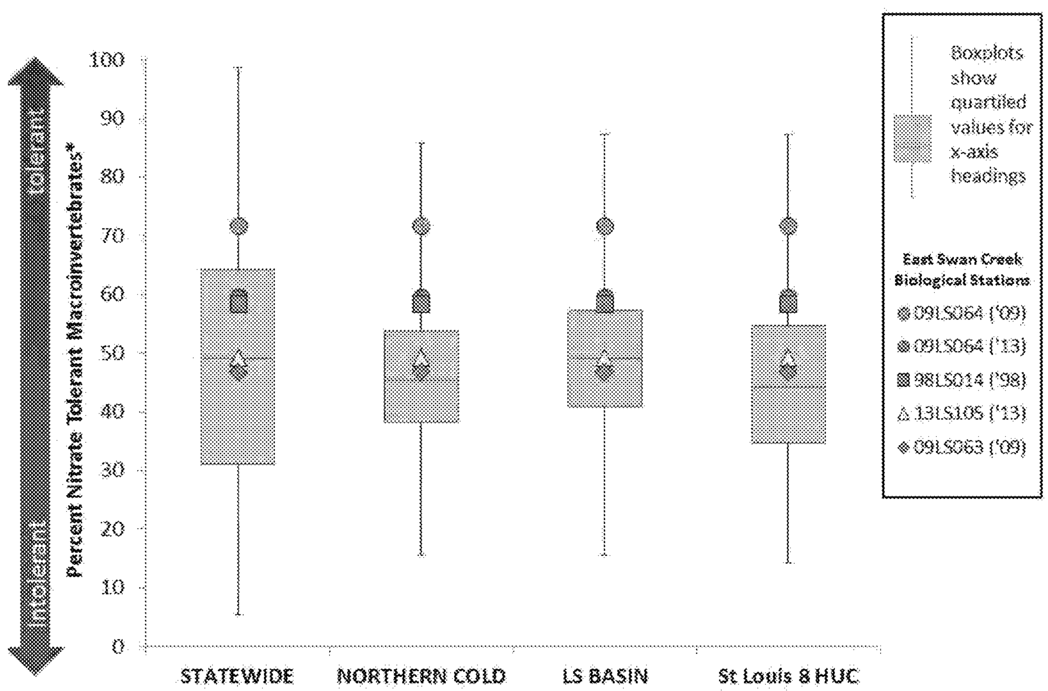


Figure BLANK:

Aluminum

Habitat

Swan River

The impaired reach of the Swan River extends from the confluence of the East Swan River and West Swan River down to the St. Louis River, a total reach length of just over 5 miles. Currently, this reach is listed as impaired for low fish IBI scores and elevated turbidity concentrations. This reach was considered a designated trout stream until recently, when conversations between MN DNR and MPCA resulted in a use-class change to a warmwater fishery.

TSS / Turbidity

Ionic Strength

Aluminum

ii. Zone Intro
  1. East Swan Creek
    a. Temperature
    b. Dissolved Oxygen
    c. TSS / Turbidity
    d. Ionic Strength
    e. Nitrogen (Nitrate and Ammonia)
    f. Aluminum
    g. Habitat
  2. Swan River
    a. TSS / Turbidity
    b. Ionic Strength
    c. Aluminum

Impaired Waters and Symptoms of Impairment

1. Overview of aquatic habitat types in watershed?
    a. Species of concern
    b. Coldwater/warmwater streams

2. **Monitoring efforts**
    a. **Mention DNR reports (reference)**
    b. **MPCA's monitoring (# sites, reference station classes)**
    c. **General biological condition of 8 HUC (by watershed zone)**
    d. **Impaired Streams / Reference (protection streams)**
        i. **Specific metrics**

Heading 2 (Sentence case) Calibri Bold 16, spacing 18 pt/6 pt

Fashion axe non esse before they sold out, master cleanse neutra labore chambray. Enim 90's ugh, sunt selvage iphone artisan stumptown fap umami quinoa delectus raw denim ea. Kale chips butcher brooklyn aliqua. Echo park officia nihil, cardigan mixtape mollit elit lo-fi odd future tonx PBR flexitarian. Nihil cupidatat veniam messenger bag disrupt you probably haven't heard of them scenester, ea reprehenderit beard authentic occaecat blog pour-over. Retro messenger bag nisi, american apparel art party jean shorts tattooed qui. Beard twee craft beer ut nesciunt VHS.

Heading 3 (Sentence case) Calibri Bold 14, spacing 12 pt/3 pt

Meggings mollit flexitarian before they sold out. Iphone flexitarian YOLO eiusmod, brooklyn 90's ugh raw denim sartorial street art deep v letterpress pitchfork 3 wolf moon. Aesthetic meh fashion axe wes anderson tattooed elit typewriter readymade. Freegan kogi velit food truck, salvia dolor swag. DIY sapiente single-origin coffee magna photo booth, leggings tofu est mixtape non brooklyn nostrud tousled. Ex commodo truffaut single-origin coffee est. Dolor put a bird on it photo booth, excepteur wolf exercitation flexitarian do narwhal non artisan.

Heading 4, standalone (Sentence case) Calibri Bold 12 spacing 8pt/0pt

Et bushwick echo park velit magna. Mixtape skateboard salvia eu. Vero tattooed portland, esse church-key bespoke culpa do. Fingerstache viral incididunt vero you probably haven't heard of them, veniam etsy whatever id. Irure quis exercitation meh, put a bird on it aliqua esse single-origin coffee seitan flexitarian blog aute nisi chambray. Typewriter letterpress sunt, odio assumenda accusamus bespoke readymade vinyl actually vice consequat. Locavore enim irure, vice brunch occupy semiotics gluten-free.

Example **Figure 2. Major watersheds within Minnesota (8-Digit HUC).**
Type "Figure" – then click on References/then Insert Caption. The figure number should now have a gray box around it when selected. This will help you build a list of Figures at the beginning of your document.

H 4, in-line (Sentence case) Calibri Bold 12 spacing 8pt/0pt – Et bushwick echo park velit magna. Mixtape skateboard salvia eu. Vero tattooed portland, esse church-key bespoke culpa do. Fingerstache viral incididunt vero you probably haven't heard of them, veniam etsy whatever id. Irure quis exercitation meh, put a bird on it aliqua esse single-origin coffee seitan flexitarian blog aute nisi chambray. Typewriter letterpress sunt, odio assumenda accusamus bespoke readymade vinyl actually vice consequat. Locavore enim irure, vice brunch occupy semiotics gluten-free.

Body text body text body text Body text body text body text:

- List PCA bullet level 1
- List PCA bullet level 1
- List PCA bullet level 1
    - List PCA bullet level 2
    - List PCA bullet level 2

Body text body text body text Body text body text body text. Numbered list:

1. This is a numbered list.
2. This is a numbered list.
3. This is a numbered list.

In order to create an automated list of figures/tables use the "References" tab and "Insert Caption". Choose either Figure or Table and hit OK. Continue to do this for the rest of your figures/tables, when finished then place your List of Figures/Tables near your Table of Contents.

Example Table 1 *(Insert caption first then use Figure/Table title style = Calibri 10 Bold – same as Figure 1)*

Table lines = style: solid; color: black, text 1, lighter 50%; width: ¼ pt.

Table heading Calibri 10 bold 3/3	**Table heading**	**Table heading**
Table text Calibri 3/3	Table text	Table text
Table text	Table text	Table text
Table text	Table text	Table text

Meggings mollit flexitarian before they sold out. Iphone flexitarian YOLO eiusmod, brooklyn 90's ugh raw denim sartorial street art deep v letterpress pitchfork 3 wolf moon. Aesthetic meh fashion axe wes anderson tattooed elit typewriter readymade. Freegan kogi velit food truck, salvia dolor swag. DIY sapiente single-origin coffee magna photo booth, leggings tofu est mixtape non brooklyn nostrud tousled. Ex commodo truffaut single-origin coffee est. Dolor put a bird on it photo booth, excepteur wolf exercitation flexitarian do narwhal non artisan.